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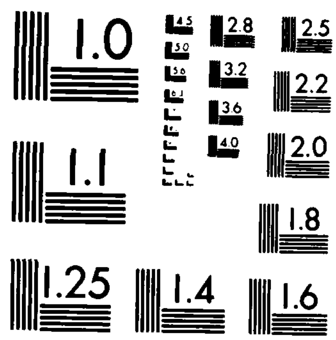
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US Army Corps
of Engineers
Construction Engineering
Research Laboratory

USA-CERL

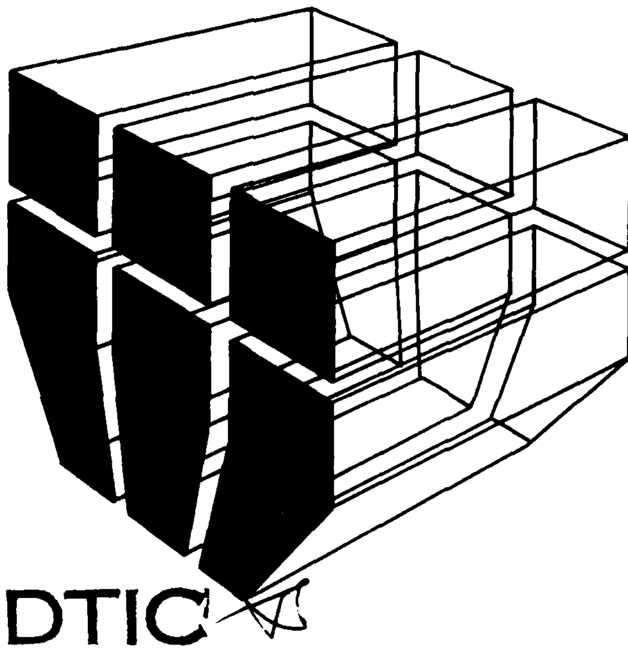
TECHNICAL REPORT M-86/10
June 1986

Investigation of Standing Seam Metal Roofing

by
Myer J. Rosenfield
William Rose
Wayne Dillner

The Army has used metal roofing systems for many years with great success. In the past, flat sheets were fabricated and seamed by hand at the jobsite. Recently, however, several new systems have been developed for which metal panels are prefabricated, shipped to the construction site, and assembled using new techniques. Current Corps of Engineers Guide Specifications are outdated with respect to these new products.

The design and method of application differ among products; still, any system to be used in Army construction must meet *critical design criteria*. In particular, the system as applied must allow for thermal expansion and contraction with changes in ambient conditions, and the Guide Specifications will have to be edited to reflect this. This report compares the features of several metal roofing systems on today's market.



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The Army has used metal roofing systems for many years with great success. In the past, flat sheets were fabricated and seamed by hand at the jobsite. Recently, however, several new systems have been developed for which metal panels are prefabricated, shipped to the construction site, and assembled using new techniques. Current Corps of Engineers Guide Specifications are outdated with respect to these new products.

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FOREWORD

This work was performed for the Assistant Chief of Engineers, Office of the Chief of Engineers (OCE), under Funding Authority Document (FAD) 2-001676, dated 7 February 1984. The OCE Technical Monitor was Chester Kirk, DAEN-ZCF-B.

The investigation was conducted by the Engineering and Materials Division (EM), U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. Robert Quattrone is Chief, EM. William Rose and Wayne Dillner are with the Small Homes Council/Building Research Council, University of Illinois.

COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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INVESTIGATION OF STANDING SEAM METAL ROOFING

1 INTRODUCTION

Background

Most Army facilities use conventional roofing systems, such as built-up roofing (BUR), that can be expensive and complicated to construct. These conventional roofing systems are often also comparatively short-lived, resulting in high life-cycle roofing costs which are difficult for already overburdened Army operation and maintenance budgets to absorb. Therefore, the Assistant Chief of Engineers has asked the U.S. Army Construction Engineering Research Laboratory (USA-CERL) to identify alternative, easy-to-install roofing systems that can improve the performance of Army roofing while reducing life-cycle costs.

One alternative to conventional systems is metal roofing. Recent advances by the metal roofing industry have resulted in a variety of new products; many systems are now prefabricated, shipped to the jobsite, and applied using several different methods.

The main function of roofs is to provide a continuous barrier between exterior and interior environments. To be effective, a roof must resist the damaging effects of the external environment for a reasonable period of time and support the loads imposed on it by wind, snow, and even foot traffic. All roofs are designed to keep out wind and weather. However, metal roofing is unique: it must keep the building weathertight while allowing for the relatively large expansion and contraction of the metal membrane.

All metals expand with increased temperature and contract with decreased temperature; the rate at which this occurs varies from one metal to another. For example, when 40-ft lengths of aluminum, copper, and galvanized steel are subjected to a 160°F increase in temperature, the aluminum will increase in length by nearly 1 in., the copper by 3/4 in., and the galvanized steel by 1/2 in. The expanding or contracting metal can exert tremendous force if it is not allowed to move freely. Therefore, the most significant problem for the manufacturer, designer, and installer of metal roofing systems is to allow for thermal movement while keeping the roof weathertight and secure from wind uplift. Some of the newer metal roofing systems show good potential for meeting these requirements.

Objective

The overall objective of USA-CERL's roofing studies is to (1) evaluate innovative roofing systems and materials to determine alternatives to BUR systems, (2) provide a way to improve Army roof performance and reduce life-cycle costs, and (3) develop guide specifications for selected alternative systems.

The objective of this report is to review and document the various types of metal roofing systems currently in use, particularly as applied to low-slope roofing.* This information will be used to update the applicable Corps of Engineers Guide Specifications (CEGS) to reflect the products now being marketed.

Approach

A literature search was conducted and manufacturers of metal roofing were contacted for specific information about their products. USA-CERL used this information to compare the various systems and to identify good features as well as potential problem areas. The report is intended to be a comprehensive review of the metal roofing systems' features. The specific systems described are to be considered as representative of the entire field.

Mode of Technology Transfer

It is recommended that the results of this investigation be used to revise CEGS-07413, *Metal Roofing and Siding, Plain*, and CEGS-07415, *Metal Roofing and Siding, Factory-Color-Finished*, so as to consider the products currently available on the market.

2 EVOLUTION OF METAL ROOFING

The history of metal roofing can be divided into two periods: before and after the introduction of the cold-rolling technique. The cold rolling process allows much longer roofing panels to be formed than were possible using conventional methods, eliminating cross-lap seams in many cases.

Labor-Intensive Methods

Before the advent of the brake press, the manufacture and application of a metal roof were labor-intensive. Every piece of metal that went on the roof was hand-formed at the jobsite and then hand-applied.

*"Low-slope" roofing, in general, means dead level up to 2 in 12 (inches).

A flat-seam roof was made up of interlocking squares of metal which were secured to the roof deck with cleats (Figure 1) or with nails driven through the seams. The seams were usually the single-lock type and would be soldered on low-slope roofs.

Metal roll roofing was assembled in the shop or on the jobsite from individual sheets of metal approximately 2 ft square. The sheets were fastened end-to-end with a single- or double-locked seam and formed into a roll (Figure 2). The single-lock seam was usually soldered (Figure 3), and the double-lock seam could be left unsoldered (Figure 4). The rolls of metal were cut to length either on the ground or on the roof. Handtools were used to bend the long edges of the cut sheets into a position that would allow a seam to be formed. The hand-formed seams used (Figure 5) were very similar to some of the machine-formed seams used today. Cleats were cut from sheet stock and used to secure the panels to the roof without penetrating the metal. This method required a solid substrate under the panels.

An improved method over hand-formed metal roll roofing was the hand- or power-operated brake press for forming the roofing panels. This method was faster and more accurate than hand-forming, but the length of panel was limited to that which could fit in the brake press. Typical profiles included flat sheets with either an inverted V or inverted U on each edge. The inverted V-type was lapped over the edge of an adjacent panel and fastened to the substrate with a cleat (Figure 6). The inverted U-type panel was lapped over the edge of an adjacent panel which was supported by a triangular batten. A screw or nail was driven through the top of the U to secure the panel (Figure 7). Once again, a solid substrate was required under the panels.

Corrugated sheets also were formed with a brake press. As before, the size of sheet was limited by the size of the press. Corrugated sheets were stronger than flat pans. The corrugated panels were able to span the distance between structural supports; thus, a solid substrate was not required, only a light frame of steel or wood purlins needed to be erected. The panels were side-lapped across one or two corrugations, and a nail or screw was driven through the top of a corrugation (Figure 8). A lead washer was commonly used to seal the fastener hole.

Cold-Rolling

Cold-rolling is a stepwise process in which a coil of sheet metal is progressively formed into a desired profile at room temperature. A coil of metal is fed through a series of rolling mills, each of which gives the sheet an additional incremental bend(s) until the final profile is obtained. Any coatings required on the final product are normally applied to the metal while it is still in coil form; thus, the coatings must be flexible enough to survive the rolling process without cracking or peeling off the metal. Cold-rolling is a continuous process; theoretically, the length of the final product is limited only by the length of the coil feeding the mill. For practicality, however, panel lengths are governed by shipping and handling constraints.

Mobile rolling mills allow metal roofing panels to be formed at the jobsite. However, mobile equipment cannot handle the heavy gauges of metal that are routinely rolled on shop equipment.

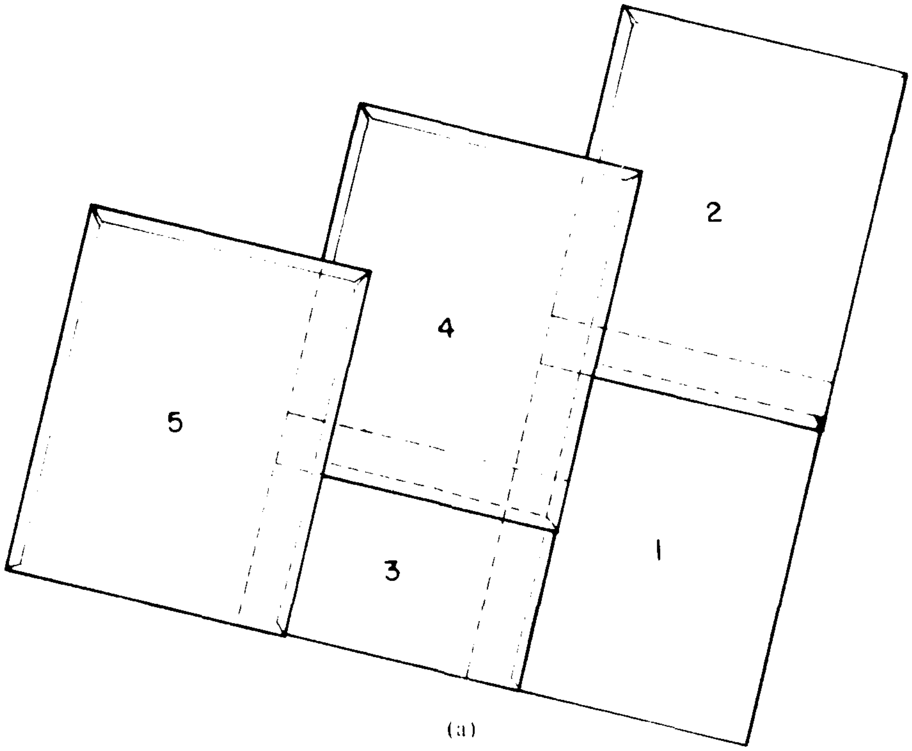
3 METAL ROOFING MATERIALS

Weatherable Metals

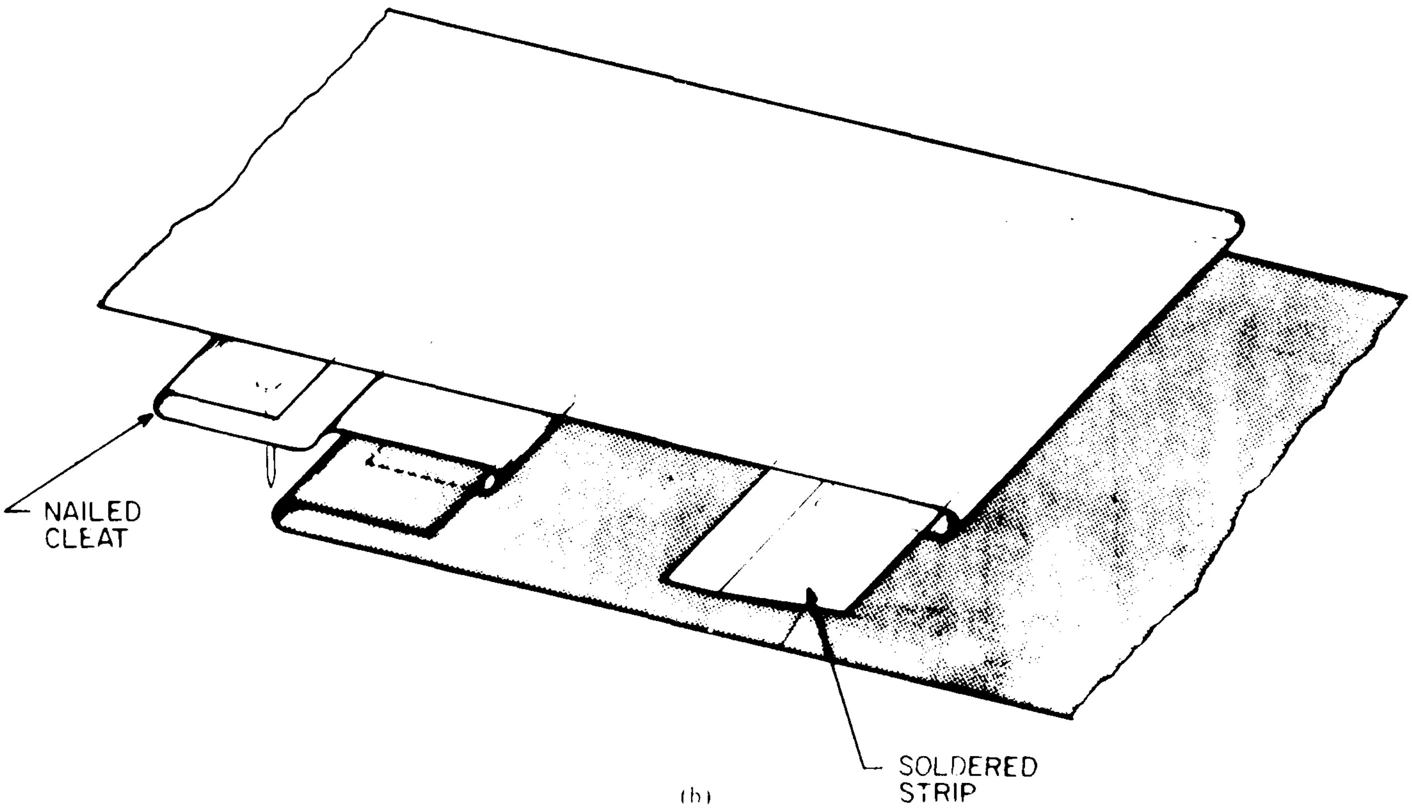
Metal roofing systems are known to provide long-lasting protection for buildings on which they are installed. Many manufacturers guarantee their systems based on the finish and/or coating used. Table 1 summarizes warranty information for representative manufacturers and selected products. Metals such as copper, zinc, aluminum, and certain steel alloys can be exposed to the weather without a protective coating. These metals initially react with the elements, but eventually, a layer of metal oxide builds up which protects the metal from further attack. In the case of copper, zinc, and Cor-ten steel, the oxide layer may take years to reach its final state. The oxide layer that forms on aluminum does so as soon as the surface is exposed to the elements, but the film is clear, colorless, and not noticeable to the eye. Stainless steel is unaffected by the elements.

Galvanic Action

Galvanic action (galvanic corrosion) is a process in which a minute electrical current is created when two different metals are in contact in the presence of an electrolyte (rainwater containing dissolved salts is one example of an electrolyte). The more reactive of the two metals will gradually corrode in order to sustain the electric current. When there is a large difference in reactivity between the two metals, the corrosion process will proceed swiftly and, when the difference in reactivity is small, corrosion will proceed slowly or



(a)



(b)

Figure 1. (a) Flat-seam roof panels interlocked (cleats and roof deck omitted for clarity); (b) flat seam detail.

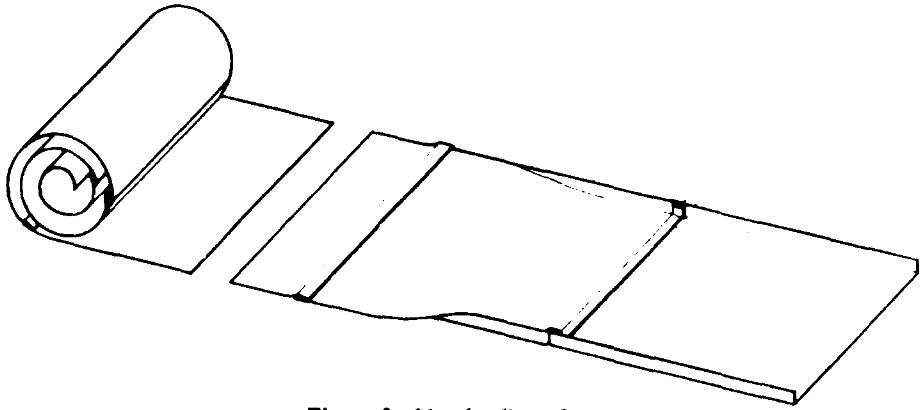


Figure 2. Metal roll roofing.

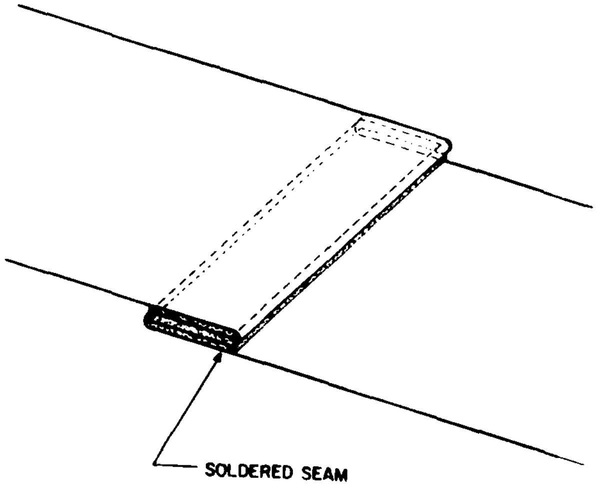


Figure 3. Soldered single-lock seam detail.

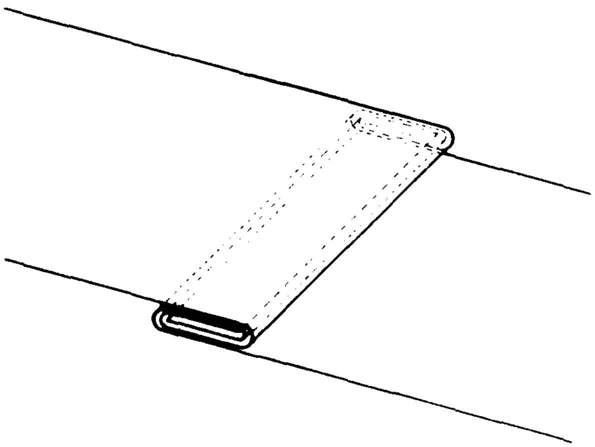


Figure 4. Double-lock seam detail.

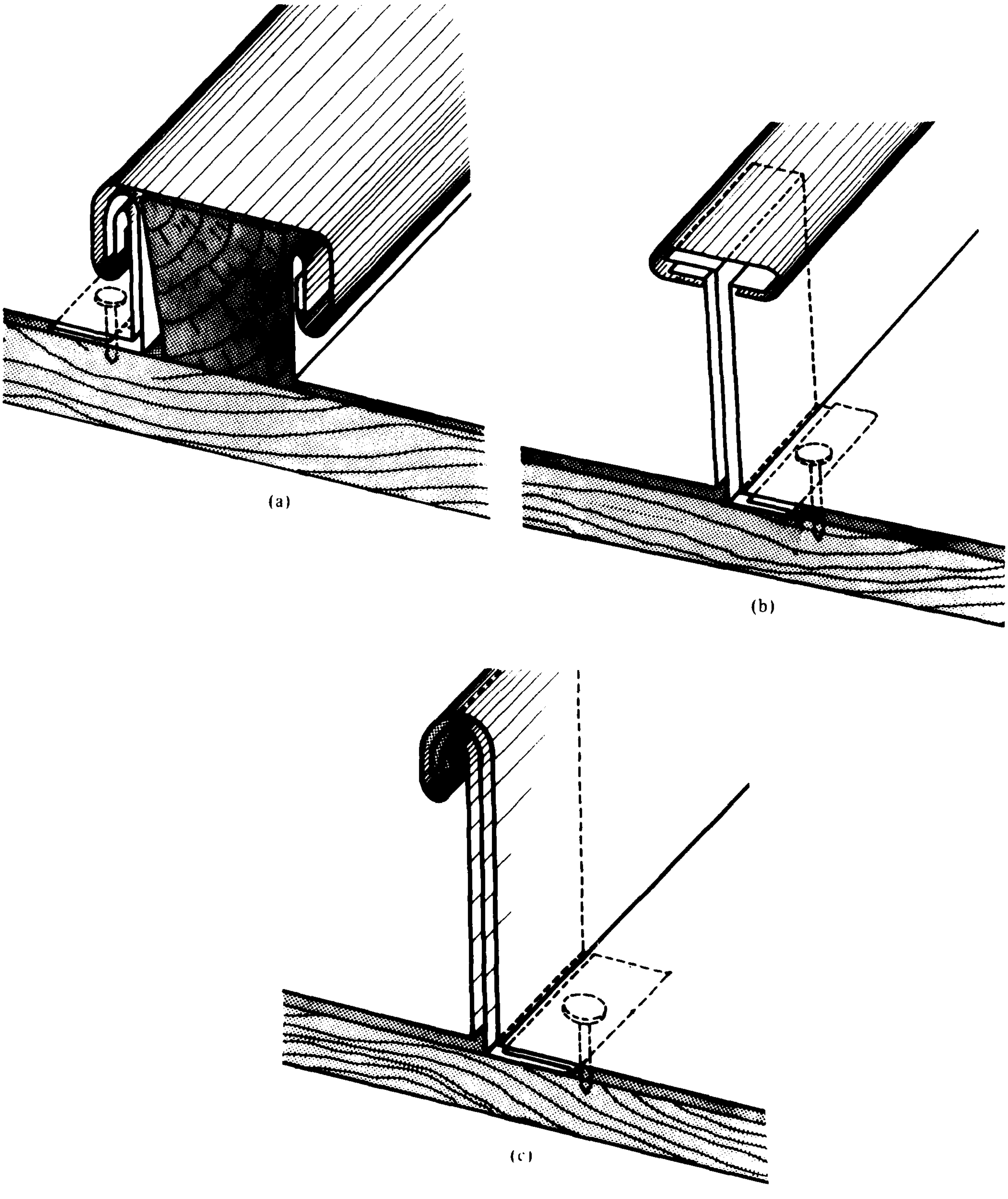


Figure 5. (a) Hand-formed batten seam; (b) hand-formed T-seam; (c) hand-formed standing seam.

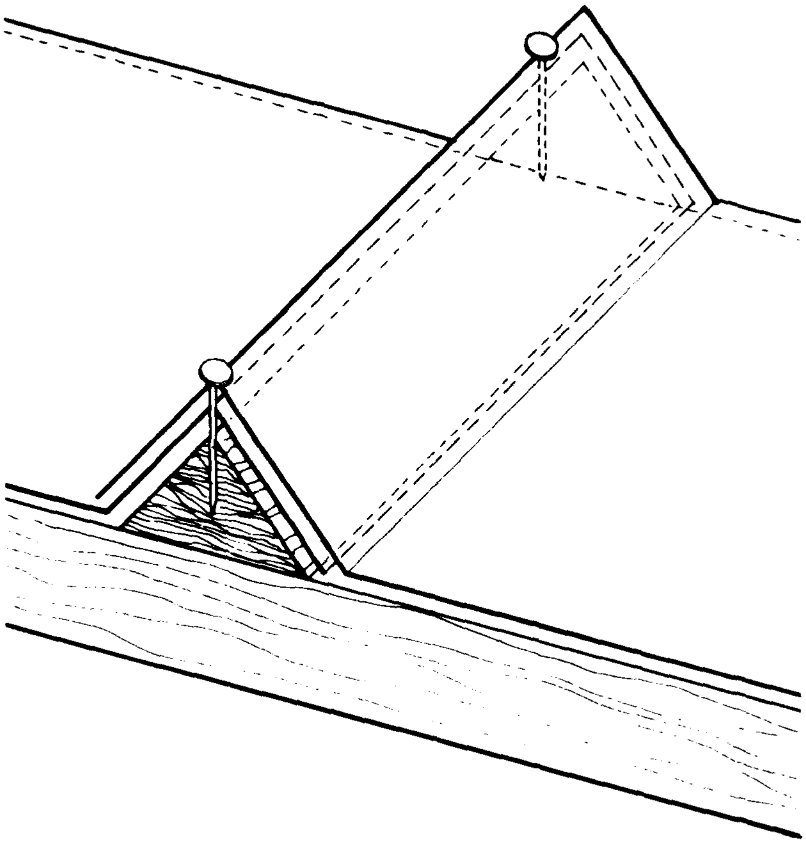


Figure 6. Seam detail on machine-formed panel- inverted V Type.

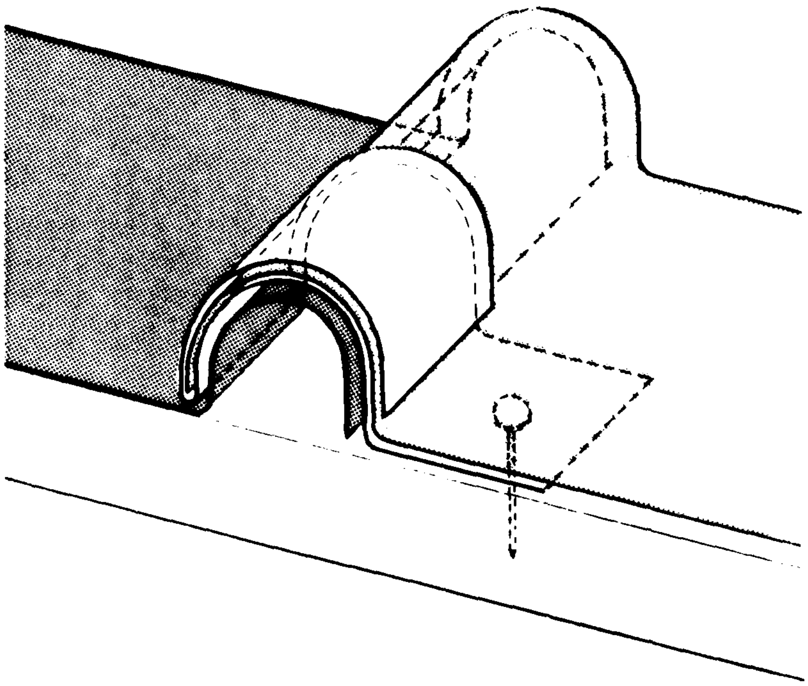


Figure 7. Seam detail on machine-formed panel inverted U type.

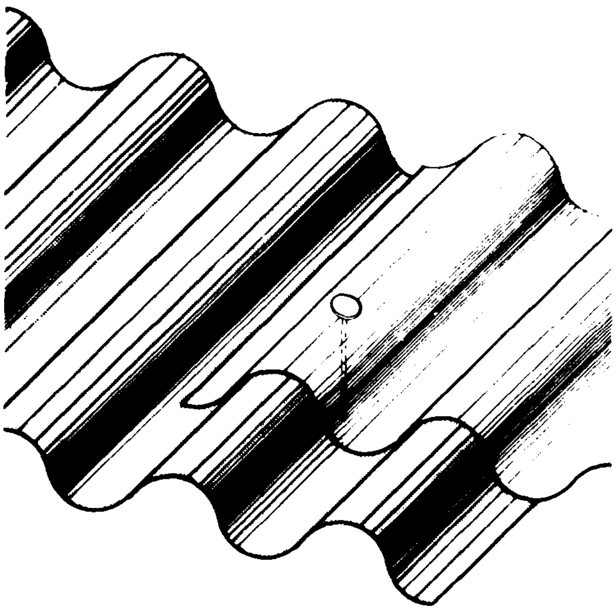


Figure 8. Corrugated panel lap joint detail.

possibly not at all. Typical roofing metals' order of reactivity is:

More reactive	1. Aluminum
	2. Zinc
	3. Steel
	4. Iron
	5. Tin
	6. Lead
Less reactive	7. Copper

An example of the damage caused by galvanic corrosion would be a piece of copper flashing secured by a galvanized steel roofing nail in a damp location. Dissolved salts or other impurities in the water would allow it to carry an electric current that would eventually destroy the zinc coating on the nail. Once the steel nail is exposed, it, too, would be destroyed by the galvanic process. The solution to this problem would be to secure the copper flashing with a copper nail or at least a high-copper-alloy nail. Copper, being the least reactive of the commonly used roofing materials, can cause galvanic corrosion in any other metal it contacts. Direct contact is not necessary; the runoff from a copper roof can have the same effect, although it may be less pronounced.

Galvanic corrosion is not confined to roofing; the process will occur whenever two dissimilar metals are in contact in the presence of an electrolyte. The best way to avoid galvanic corrosion is to avoid putting different metals in contact in damp or wet conditions. If this situation is unavoidable, paint or some other method should be used to isolate one metal from the other.

Copper

For centuries, copper has been the metal of choice for roofing important structures due to its simple, natural beauty and extreme durability. A properly applied copper roof can last for hundreds of years. For example, had it not been destroyed in World War II, the copper roof on Hildesheim Catheral in Germany (placed in 1230) would probably still be in service. Portions of this roof had never needed repair.

The development of the familiar green patina on a copper roof is a three-step weathering process that takes many years to complete. Sulfur compounds and carbon dioxide (CO_2) in the atmosphere (mainly from the combustion of fossil fuels) are the primary causes of the weathering. As soon as the copper is exposed to atmospheric moisture, a copper oxide film begins forming on the surface. Initially the film may appear to be a variety of rainbow-hued colors, but this is only an optical effect caused by the very thin oxide film. As the oxide film increases in thickness, it becomes a uniform brown color. This film is not corrosion-resistant and thus is still vulnerable to attack by sulfur compounds and carbonic acid in the atmosphere. As corrosion proceeds, cuprous and cupric sulfides and carbonates begin forming among the copper oxide products. The sulfide products are darker in color than the oxide products. Like the oxide film, the sulfide products are not particularly corrosion-resistant. The final step in the weathering sequence is the formation of the green layer which results from the conversion of the copper sulfide and carbonate products. The layer may begin forming in as few as 7 years in an industrial region (which has a high level of atmospheric sulfur) or as many as 14 years in a rural area (with a relatively low level of atmospheric sulfur). Another key factor affecting the weathering rate is the amount of rainfall in the region, because rain is a good vehicle for bringing atmospheric sulfur and CO_2 into contact with the copper roof. The final composition of this patina can be either basic cupric carbonate ($CuCo_3 \cdot Cu(OH)_2$), dibasic cupric sulfate ($Cu_3H_4O_8S$), or any combination, as well as many other compositions.

Since the time required to achieve the final green patina on a copper roof is rather long, chemical treatments have been sought which would accelerate the weathering process. The most common treatments use chloride salt solutions or sulfate solutions that are either sprayed, brushed, or sponged onto the roof.

Table 1

Representative Manufacturer Warranties for Selected Products[1]

Manufacturer	Roofing System Name	Base Metal	Protective Coating/Finish	Warranty
AFP/SPAN	*Standing Seam & Batten*	24-ga. steel[2]	Hot-dipped galvanized Kynar™, or Weathering Copper™ System	20-yr
American Buildings Co.	Standing Seam II	24-ga. steel	Paint, aluminized, or Doubl-lam™ System	20-yr (materials & weather-tightness)
Architectural Manufacturing/Architectural Panels, Inc.	Roof-Lok	18- to 26-ga. steel or stucco-embossed aluminum (0.032")	Galvanized, aluminized, stainless steel, copper (some with paint)	20-yr[3]
Armco	STEELOX-CF	24-ga. steel	Aluminized Steel Type 2	20-yr[4]
ASC Pacific, Inc.	Klip-Rib	24-ga. steel	Zincalume	20-yr limited
Dean Steel Buildings	XL Standing Seam	24-ga. steel	Galvalume	No information supplied
Epic Metals	Epic Structural Standing Seam	22- or 24-ga. steel	Hot-dipped aluminum or Galvalume	1-yr[5]
Fabral/Alcan	Fabral Standing Seam	24- or 26-ga. steel or 0.032" aluminum	Aluminum-zinc alloy, or galvanized with paint	Contact manufacturer (address in appendix)
Follansbee	Terne-Coated Stainless Steel Standing Seam	0.012", 0.015", or 0.018" stainless steel	Terne-Coat™	20-yr
H. H. Robertson, Inc.	Robertson Total Performance	22- or 24-ga. steel	Versacor™ System[6]	20-yr[7]
Metal Building Components, Inc.	MBCI Traditional Series	22- to 26-ga. steel or 0.040" aluminum	Galvalume plus Dexstar™ 850 System[8] or Kynar™ 500	20-yr on bare Galvalume and Kynar 500; conditional on the Dexstar System (case-by-case basis)
Rib-Roof Industries	Rib-Roof	18- to 28-ga. steel	Hot-dipped galvanized with Duranar™ 200 fluoropolymer paint	20-yr (special order basis)
Roof Systems, Inc.	RS-18	24-ga. steel	Aluminized, Galvalume, Kynar™ 500, aluminum, or stainless steel	20-yr
Vulcraft	Vulcraft Standing Seam	24-ga. steel	Galvalume	20-yr
Zip-Rib, Inc.	Zip-Rib Roofing	0.032" or 0.040" Base	Bare or painted	20-yr limited

[1] Specifications are for panels only. Most warranties cover only the finish system unless otherwise specified; typical warranties are against rupture, structural failure, and perforation under normal atmospheric conditions. Additional information may be available by contacting individual manufacturers (addresses in appendix).

[2] Other gauges are available with modified 20-yr warranties.

[3] Also offers warranties on installation up to 20-yr and on coating from 10- to 20-yr on a case-by-case basis.

[4] An optional weathertightness warranty also can be arranged.

[5] Covers manufacturing defects on all materials and mechanical parts.

[6] Versor is a layered system using hot-dipped zinc/epoxy base coat/finish coat.

[7] Company offers a 20-yr "conditional agreement," based on a field study of site. Also offers 5-yr protection against leakage and 5- to 10-yr guarantee for fading, depending on finish.

[8] Dexstar is a thermoset silicone polyester coating system.

The success of the chemical treatment often depends on the weather at the time of application. One particular treatment, in which an ammonium sulfate solution is used, requires a relative humidity of at least 80 percent while six to eight spray applications are made. A method that uses ammonium chloride requires dry weather for a 72-hr period while the treatment is on the roof. It should be emphasized that the results obtained by any artificial "weathering" process are highly variable. Frequently, a convincing-looking patina is achieved by artificial means, only to have it fade after a few years to one of the intermediate brown shades of the natural weathering process.

Aluminum

A mill-finish aluminum surface will very rapidly develop a stable oxide coating that protects it from further corrosion. The oxide film is quite thin–on the order of a few millionths of an inch thick–and is clear and colorless; thus, the surface appearance does not change much with age.

Bare aluminum surfaces are very good reflectors of radiant heat. A bright new aluminum surface will reflect up to 98 percent of the radiant heat that strikes it. Even after weathering for years, the surface will still reflect 85 to 95 percent of the radiant heat striking it. This means that a bare aluminum roof will reflect most of the sun's radiant energy, thus holding down the under-roof temperature. If the underside of an aluminum roof is left unpainted, it will also reflect radiant heat onto the building's occupants for increased warmth in cold weather.

Zinc

Zinc is fairly resistant to corrosion, which is one reason it is used as a protective coating for steel (see *Galvanized Steel* below). When zinc is exposed to weather, a dull-gray zinc carbonate film forms which protects the remaining zinc from further corrosion. Seacoast atmospheres tend to be very hard on zinc, causing it to degrade much faster than it would under less alkaline conditions.

Sheet zinc has the highest coefficient of thermal expansion of all the metals commonly used for roofing. Zinc's coefficient of thermal expansion is nearly twice that of stainless steel and copper, and almost three times that of galvanized steel. When sheet zinc is used as a roofing material, all details must take into account the considerable expansion and contraction that will occur.

Stainless Steel

Stainless steel is a steel alloy that contains at least 11 percent chromium along with other alloying elements such as nickel, manganese, and molybdenum. The higher the chromium content in the alloy, the more resistant it is to corrosion; some stainless steel alloys contain nearly 30 percent chromium. The type of stainless steel most commonly used for roofing products is Type 18/8, which contains 18 percent chromium and 8 percent nickel as the main alloying elements.

Stainless steel does not have copper's long history as a roofing material, nor does it develop the rich patina that makes copper so desirable. Still, for an extremely durable roof in a tough industrial atmosphere, stainless steel would be a good choice. Stainless steel is stronger than most other weatherable metals; therefore, thinner gauges can be used than, for example, with copper or zinc.

Cor-ten Steel

Cor-ten is the registered tradename for a steel alloy produced by United States Steel. The outer surface of this material is intended to corrode during the first few years of exposure. The tight oxide layer that builds up eventually protects the metal from further corrosion. The runoff from a Cor-ten steel surface in its weathering stage is messy and can stain many materials. Fasteners used to secure Cor-ten also should be made of Cor-ten to avoid problems with galvanic corrosion. Experience has shown that Cor-ten must be installed in a severe atmosphere so the protective oxide will form quickly; this material can deteriorate in mild atmospheres.

Alloy Coatings

Two types of alloy coatings are applied, depending on the approach: (1) a less reactive alloy will corrode more slowly than the base metal and (2) a more reactive alloy will corrode sacrificially at breaks in the coating. A problem with the first method arises when a break occurs in the alloy coating. Moisture will turn the break into a galvanic cell and the base metal will corrode rapidly (since it is more reactive than the alloy coating); the roof membrane will soon be penetrated. The second method does not present this problem because the base metal is less reactive than the alloy coating. The alloy coating will corrode sacrificially at a break in the coating, leaving the base metal intact to provide a barrier to the elements.

Galvanized Steel

Galvanizing deposits a coating of zinc on steel. Zinc is a more reactive metal than steel, yet will last much longer under direct exposure to the elements because it does not rust. The steel will be protected at breaks in the coating by a sacrificial corrosion of the zinc coating.

Galvalumed Steel

Galvaluming is a process patented by Bethlehem Steel in which a coating of aluminum-zinc alloy is deposited on steel. The aluminum-zinc alloy has better weathering characteristics than pure zinc; thus, Galvalumed steel usually lasts longer than galvanized steel. As with galvanized steel, Galvalumed steel will be protected at breaks in the coating by sacrificial corrosion of the aluminum-zinc alloy.

Zincalumed Steel

Zincaluming is a process patented in Australia and is identical to Galvaluming. Use of Zincalumed steel is common on the West Coast of the United States.

Aluminized Steel

Aluminizing is a process used by Armco Building Systems in which a layer of pure aluminum is deposited on steel. The aluminum coating has good weathering characteristics and will, by sacrificial corrosion, protect the base steel at breaks in the coating. Under identical conditions, aluminized steel will take longer to corrode than will galvanized steel.

Terne-Plate

Terne metal, a product of Follansbee Steel, is an alloy of lead and tin that extends the life of a base metal (usually prime copper-bearing steel or stainless steel) by weathering at a much slower rate than the base metal. Terne metal, being less reactive than prime copper-bearing steel, will cause the steel to corrode rapidly at any breaks in the coating. To provide greater weather protection, Follansbee Steel recommends that Terne-coated copper-bearing steel be painted with a brush-applied oil-based exterior paint as soon as practical after installation. Stainless steel is frequently used as the base metal because it is affected less by galvanic action should the Terne coating break. Terne-coated stainless steel requires no additional coating for weather protection, although it can be painted if desired.

Anodic Coatings

Anodizing is an electrochemical process used to form a heavier-than-normal corrosion-resistant oxide coating on aluminum. The aluminum to be anodized acts as the anode in an electrochemical cell. Conventional anodizing processes use organic dyes to give the coating its color (undyed aluminum oxide is a colorless film). Organic dyes can eventually fade after long exposure to ultraviolet (UV) radiation and weather. Color-In, an anodizing process patented by Coil Anodizers Division of Lorin Industries, uses inorganic metal oxide pigments deposited at the base of the aluminum oxide coating. The inorganic pigments will not fade due to UV or weather exposure.

Organic Coatings

Organic coatings are the various paints that have been developed for use on metal roofing panels. Organic coatings often are applied over an alloy coating such as galvanized metal, Galvalume, or Zincalume while the metal is still in coil form. In this way, the protective qualities of the alloy coating are "held in reserve" under the organic coating, increasing the roof panel's service life.

Accelerated weathering tests are performed on organic coatings to indicate how well the coatings will perform when placed in service. Two of the most useful ratings a coating will receive as a result of these tests are the color change and chalk ratings. Besides corrosion, color change and chalking probably are the most visible indications of aging for a painted metal surface. Chalk is basically deteriorated paint; consequently, the less a finish chalks, the longer it will last. Chalk ratings range from 8 (best) to 0 (worst) in increments of two. A chalk rating of 8 over the life of the coating would indicate very little chalking has occurred. A rating of 6 indicates heavier chalking, but possibly acceptable if the coating is white or some other very light color (on which chalk would not be obvious). A chalk rating of 4, 2, or 0 indicates an unacceptable amount of chalking would occur over the life of the coating. A perfect color change rating would be 0, indicating no measurable change in color over the life of the coating. A color change rating of 1, 2, or 3 indicates excellent color stability, and 4 or 5 is still quite good. A color change rating between 0 and 5 would be acceptable over the life of the coating.

Polyester Enamel

Polyester enamel is the least expensive and the least durable organic coating available. For example, most automobile finishes are of polyester enamel, and most manufacturers will offer no more than a 5-year guarantee on this type of coating. Polyester enamels are typically applied at a dry film thickness (DFT) of approximately 1 mil.

Silicone-Modified Polyester

Silicone-modified polyesters are polyester enamels that have been modified by adding silicone-based polymers. Not all silicone-modified polyesters are the same; the performance of a particular coating depends on the formulation. A guarantee of up to 25 years is available on panels coated with ceramic-pigmented silicone-modified polyester from at least one manufacturer. Other manufacturers offer 10- and 20-year guarantees on their formulations. Typically applied at a DFT of approximately 1 mil, the silicone-modified polyesters have good color retention and are fairly resistant to fading and chalking.

Fluorocarbon Polymers

Fluorocarbon polymers, also called "Kynars" (after the main component of the coating), are among the "premium" coatings used when excellent color retention, film adhesion and flexibility, and resistance to fading, staining, and abrasion are desired. Kynar resin is a polymer compound manufactured by Penwalt Corporation. The performance of a fluorocarbon polymer coating depends mainly on the percentage of Kynar resin it contains. Manufacturers of panels coated with fluorocarbon polymers usually offer a 20-year guarantee on film integrity and fading. The range of available colors is somewhat limited because many of the more colorful organic pigments have a relatively short life and thus cannot be used. Fluorocarbon polymers usually are applied at a DFT of approximately 1 mil.

Plastisols/Organosols

Plastisols and organosols belong to the vinyl dispersion family of coatings. The high solids content of these coatings allows them to be applied in relatively heavy film thicknesses (from 3 to 8 mils). The heavy film thickness allows decorative patterns to be embossed in the coating, rather than in the base metal. Manufacturers claim these coatings are highly resistant to abrasion, chemical attack, and seacoast environments.

Urethanes

Manufacturers of urethane coatings claim urethanes are ideal for recoating faded and corroded finishes in the field because of these coatings' ability to adhere to badly weathered surfaces. Urethanes also are used as factory coatings for roof panels. Manufacturers promise excellent resistance to UV radiation, chemical attack, abrasion, and seacoast atmospheres. Two basic types of urethane coatings are produced: a one-part moisture-curing type that cures by drawing moisture from the air and a two-part chemical-curing type that must be mixed from two separate components before application. In field-recoating corroded or exposed metal, the one-part type is recommended as a primer because it adheres extremely well in those situations, but it can be used as topcoat as well. A primer coat may not be required if the existing finish is merely faded (with no rust or bare metal). Urethanes usually are applied at a DFT of 1 to 2 mils.

Acrylic Film

Korad is the tradename of an acrylic film approximately 1.18 mil thick which is heat-laminated to galvanized steel. The film resists UV weathering and remains flexible. However, some applications have delaminated from the base metal due to poor control of the lamination process early in the product's history; this problem is said to have been corrected in recent years. The principal laminator of Korad now offers a 20-year warranty on the product.

4 METAL ROOFING APPLICATION

The application of a metal roof can be considered in three separate stages: substrate preparation, membrane application, and terminations. Substrate preparation consists of erecting the purlin framework or solid deck and all other materials that go under the roof membrane. Membrane application involves laying and locking the roof panels. In the final step—terminations—the curbs, ridge caps, gutters, and any other finishing elements are installed. Once applied, the metal roof will need occasional maintenance and repair. When it reaches the point at which rust begins to form or the finish is faded badly, a new finish can be applied to extend the roof's useful life considerably.

Substrate Preparation

Two different roofing situations occur: a new structure that requires a roof or an existing structure that needs to be reroofed. In the second case, the roof membrane to be recovered may be the built-up or metal type.

To install a roof on a new structure, two different types of substrates can be used: solid or purlin. The solid substrate can consist of wood sheathing (Figure 9) or metal decking (Figure 10).

Rigid insulation can be placed on top of the sheathing (or decking) or blanket insulation can be secured underneath. Certain types of roofing panels require a solid substrate for support. A solid substrate provides structural bracing for the building and occasionally is

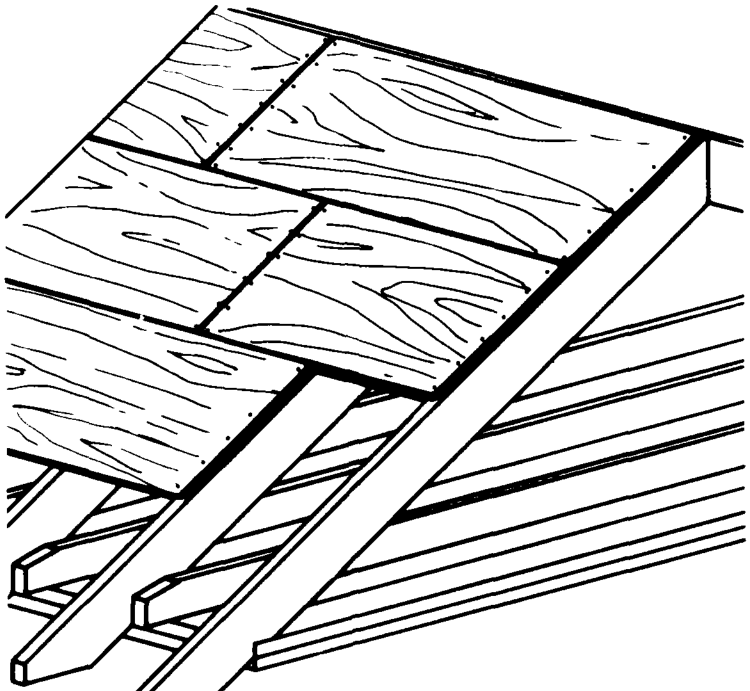


Figure 9. Typical solid substrate using wood sheathing.

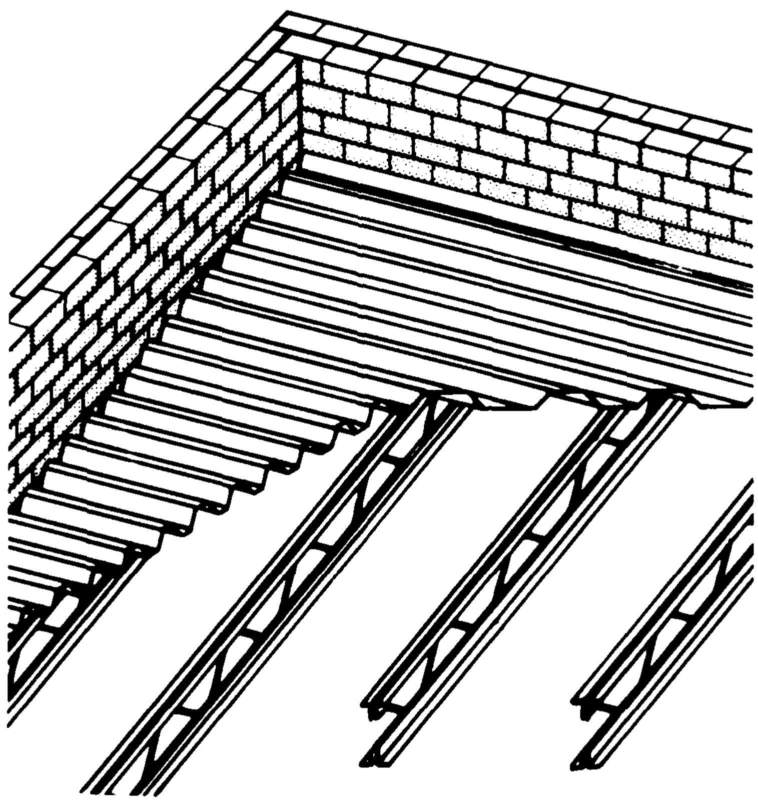


Figure 10. Typical solid substrate using metal decking.

used for that reason under roofing panels that do not actually require continuous support. The purlin substrate can be used only under the structural type of panel, which has spanning capabilities. The purlins, commonly light-gauge C- or Z-section steel members, usually are spaced 5 ft on-center, spanning between rafters or roof trusses (Figure 11). Blanket or rigid insulation can be laid over the purlins as desired; the insulation's strength and support requirements should be considered when determining purlin spacing. A properly located vapor retardant is important in either type of substrate system to avoid problems with condensation in the insulation or on the undersides of the roof panels.

The most common reroofing job is to install a metal roof over a worn-out BUR. The old roof membrane can be left in place unless water has penetrated it and soaked the insulation below, in which case the roof membrane and insulation should be stripped away. The old insulation and roof membrane cannot be relied on to provide a firm, stable base for the new roof and, in addition, any contained moisture could cause problems for the new roof system if the roof cavity is not vented properly. Stripping off the old BUR adds considerably to the cost and labor of installing a new roof and negates one of the attractive features of a retrofit metal roof the ability to install it right on top of the old roof with minimal disturbance to activities inside the building. If the old roof membrane can be left in place, the loose ballast is usually removed to reduce the dead load. If the old roof is flat, a wood or metal framework will have to be constructed to slope the new roof for drainage (Figure 12). Purlins are fastened to the framework and the roof is finished in the normal way. If the old roof already has enough slope, it is not necessary to construct a framework for the purlins; they can be attached directly to the roof surface at the proper spacing (Figure 13). If a thick layer of insualtion will be used, the purlins may have to be raised up on blocking.

As metal roofing sees more common use, the need to reroof structures with worn-out metal roofs will also become more common; the old metal roof will become the substrate for the new metal roof. This situation raises questions about the compatibility of materials used on the old and new roof systems and the old roof's structural integrity. As explained earlier, galvanic corrosion occurs when two dissimilar metals are in contact in the presence of an electrolyte. Moisture that might condense between the old and new roofs could act as the electrolyte and, if the metals are not compatible, cause hidden galvanic corrosion of the support clips or old roof. Moreover, a badly corroded or deteriorated metal roof may need to be removed entirely before installing the new metal roof because it cannot provide a structurally sound surface for attaching the new roof.

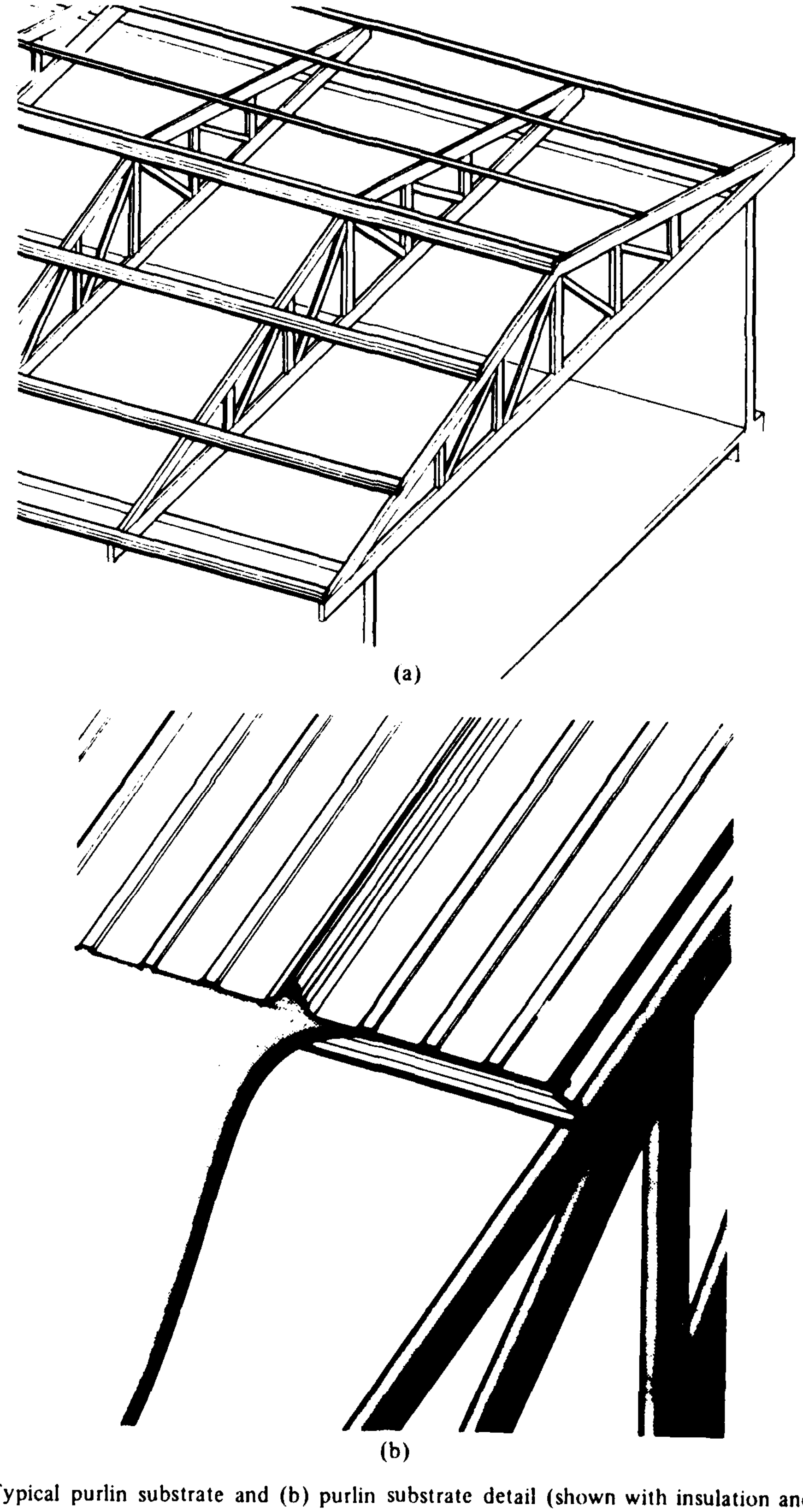
If the old roof membrane is to be left in place, another concern is how well it is attached to the building itself. The new roof cannot be expected to achieve a high wind uplift rating if the original roof is not able to achieve that same rating. Tests could be performed on the old roof to determine the pullout strength of typical fasteners.

Membrane Application

Aside from the fact that different roof panels have a variety of methods for forming their side lap seams, the main difference in applying various roof panels is in how they are laid—from left to right or right to left across the slope of the roof. If the roof slope is short enough to be covered by a single length of panel (rather than requiring two or more panels to be end-lapped), the direction of application is arbitrary and can be left to the designer's and installer's judgment. If the roof slope is long enough to require two or more roof panels to be end-lapped, the direction of panel-laying usually will be dictated by the way in which the ends of the roof panels are prepared for the end lap. Most manufacturers factory-prepare the ends of panels to be lapped, either by trimming away part of the seam on one panel or swaging or die-setting the end of one or both panels. Factory preparation of the panels makes for a close-fitting end lap and, consequently, a better seal, without requiring the field installers to do any trimming.

Once the direction of installation has been determined (left to right or right to left), the first roof panel or row of panels is laid at, or within, a few inches of the edge of the roof. The impo tant step at this point is to be sure that the first panel or row of panels laid is exactly parallel to the slope of the roof. Slight inaccuracies in alignment can be corrected as additional panels are laid, but the best method is to avoid misalignment in the first place. Some manufacturers offer a spacing gauge which is used to make sure the roof panels are not inadvertently stretched or shortened in width as they are applied. Panel alignment should be checked often as installation progresses. It is not difficult to skew a relatively flexible metal panel that may be 50 or 60 ft long.

To avoid damage, certain precautions should be observed in handling the roof panels before installation



(a)

(b)

Figure 11. (a) Typical purlin substrate and (b) purlin substrate detail (shown with insulation and roof panels in place).

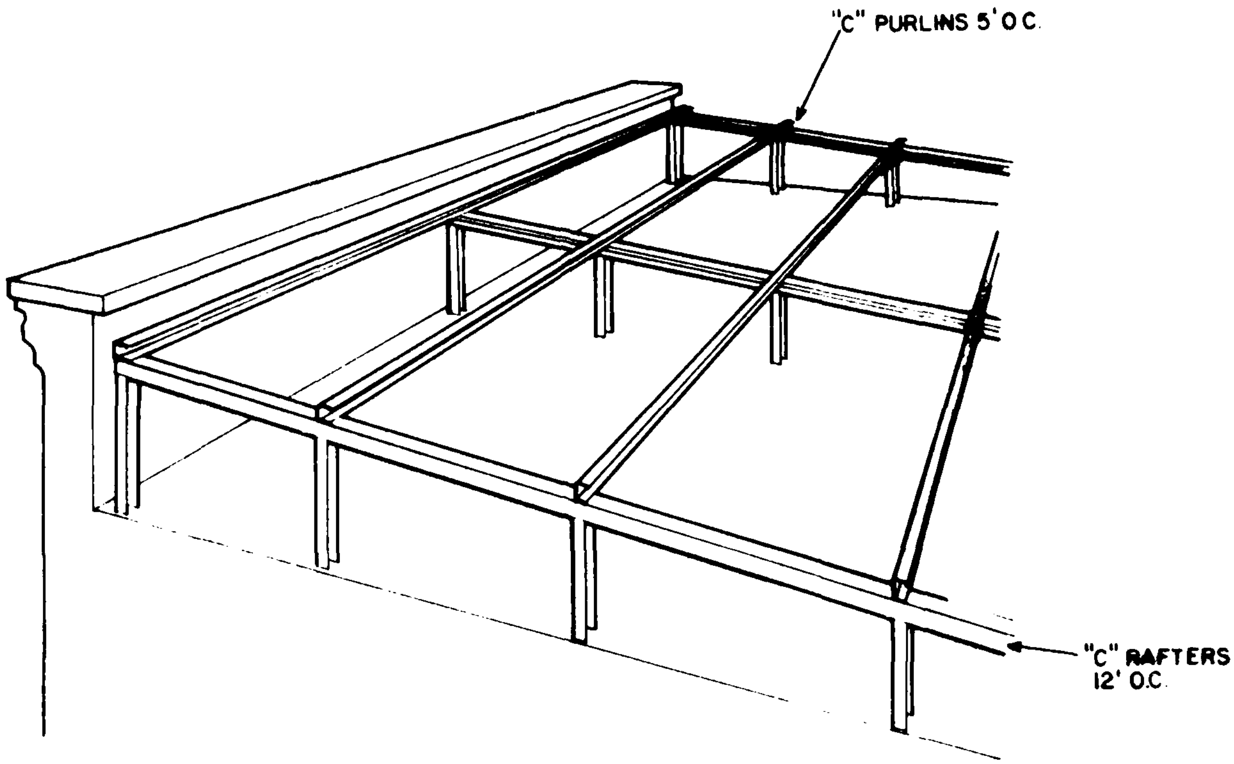


Figure 12. Framework with purlins attached to create slope over flat built-up roof.

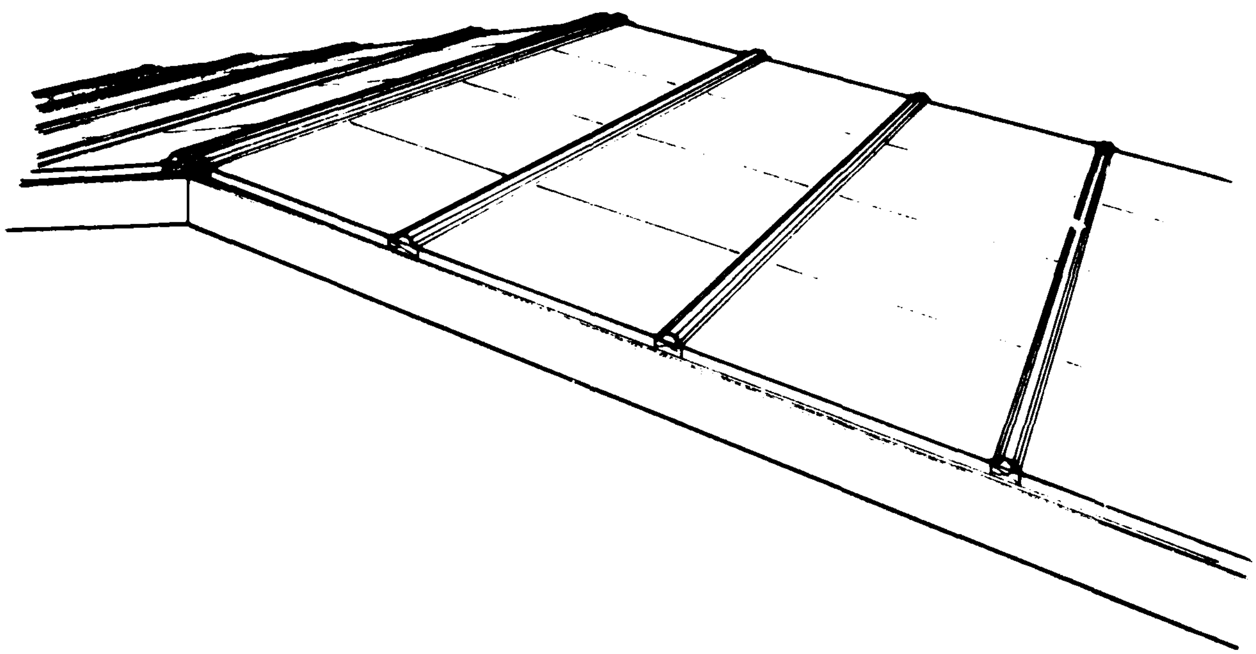


Figure 13. Purlins on sleepers applied directly to sloped built-up roof (shown with rigid insulation boards laid between purlins).

Most manufacturers provide very specific instructions on how their panels should be stored and handled. For example, most say that adequate support should be provided when bundles of long panels are being off-loaded from the truck; support usually is required at the third points of a bundle. In addition, if the panels must be stored outdoors, they should be placed off the ground on angled blocking so that water can drain freely. The stack of panels should be covered with a breathable tarp that will keep rain off the panels yet allow air to circulate (lessening the buildup of condensation). White rust or staining will tend to occur on tightly stacked panels between which moisture is trapped. Panels should not be dragged over one another or on the ground; rather, they should be lifted off the bundle and carried to avoid scratches that may cause the finish to fail prematurely. A common procedure during installation is to place bundles of panels at intervals on the roof purlins or deck. However, if the bundles are quite large, the roof structure can be overloaded in spots unless extra support is added.

Terminations

Terminations are components such as ridge caps, curbs, flashings, gutters, and valleys which seal around openings or irregularities in the roof membrane and carry water to the building exterior. Several representative terminations were reviewed for the study. Listed with the description of each device is the manufacturer, for whom more information is given in the appendix.

Curbs and Pipe Flashings

These terminations seal around penetrations through the roof panels. Curbs are used around larger, usually rectangular penetrations such as skylights, rooftop equipment, and ventilation ducts; pipe flashings, as the name implies, are used to seal around pipe penetrations (such as a plumbing vent stack). Most pipes, ducts, and equipment items that penetrate the roof remain in response to thermal expansion and contraction. The curb or pipe flashing must allow for this relative movement while remaining weathertight. A skylight usually will "float" with the roof panels, so relative movement is not a problem with a skylight curb. An important feature for a wide curb is a diverter on the curb's upslope side. The diverter directs roof drainage around the curb rather than allowing it to build up against the curb.

1. *Pipe Flashing at Panel Rib.* Pipe penetrations must be centered (or nearly so) on the rib to allow maximum movement of the roof relative to the pipe (Figure 14). The rubber boot should provide a tight seal between the pipe and sleeve. The location of a pipe penetration is not always at the roofer's discretion; thus, the pipe may not be centered in the sleeve. (H. H. Robertson Co.)

2. *Sheet Steel Pipe Flashing Away From Panel Rib.* The seal may not be as tight on a sheet steel flange as it is with the rubber-booted-type detail in numbers 1 above and 3 below (Figure 15). However, as long as the upper skirt overlaps the lower sleeve at least an inch or so, the sheet steel flange should perform adequately. The long-term performance of this detail depends heavily on the sealant between the base flange and the roof. (ASC Pacific, Inc.)

3. *Rubber Gasketed Pipe Flashing Away From Panel Rib.* Many installers use a device of this type to seal a pipe penetration (Figure 16). The rubber collar must be field-cut to the proper diameter so it will seal snugly around the pipe. The hole in the panel must be large enough to allow the panel to move relative to the pipe. (Armco Building Systems)

4. *Sheet Metal Pipe Flashing at Panel Rib.* The hole in the roof panels and diameter of the lower sleeve must be large enough to allow the roof to move relative to the pipe (Figure 17). Reliability of the metal rib closure is the key. The upper skirt must overlap the lower sleeve enough to keep out wind-blown rain. (ASC Pacific, Inc.)

5. *Rubber Gasketed Pipe Flashing at Panel Rib.* This detail (Figure 18) requires a very flexible flashing material to seal around the rib. It can be difficult to seal completely between the flashing and the roof panel. The recommended clearance around the pipe (1/2 in.) will leave no room for thermal expansion and contraction of the roof relative to the pipe if the hole is not located accurately. (Rib-Roof Industries)

6. *Pipe Flashing at Ridge Cap.* Aluminum flashing is clamped and sealed to the pipe and is also screwed to the ridge cap; longitudinal thermal movement of the ridge cap is thus prevented at this point (Figure 19). Buckling of the ridge cap due to thermal expansion and contraction should not be a problem as long as the ridge cap is in sections no longer than 10 to 12 ft. (Zip-Rib, Inc.)

7. *Curbed Opening Without Diverter.* This detail lacks a diverter on the upslope side of the curb to direct water to either side of the curb (Figure 20). On an opening of the size shown here, a diverter is a

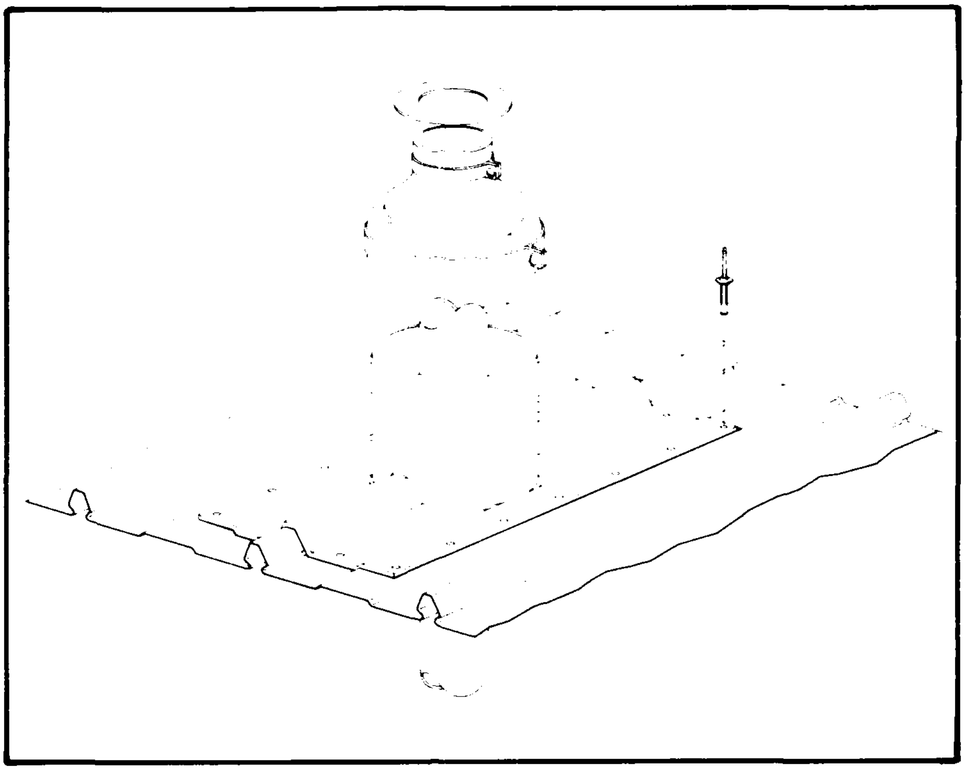


Figure 14. Pipe flashing at panel rib.

necessity, especially when one entire panel width is blocked. Some relative movement is possible between the roof and curb since the two are not connected physically. (Roof Systems, Inc.)

8. *Curbed Opening With Diverter Example 1.* Relative movement is possible between the curb and the roof since the two are structurally independent of each other (Figure 21). The diverter directs water to either side of the curb. The collar flashing does not overlap the floating curb by much in the vertical dimension, installed height of the structural curb assembly is critical to avoid a gap where rain could enter. (Vulcraft/Nucor Corp.)

9. *Curbed Opening With Diverter Example 2.* The roof moves independently of equipment on the curb. The diverter directs water around the curb. This detail has the same problem as number 8 above: the apron flashing overlaps the floating curb by a relatively small vertical distance (section D-D in Figure 22); thus, rain could enter if the structural curb assembly is installed too high. (H. H. Robertson Co.)

Gutters

Gutters are terminations used to collect runoff from the roof and direct it to a downspout where it can be drained. Both the gutter and downspout must be sized for the roof area being drained. The gutter must have at least a minimum slope so water will drain efficiently. Snow or ice that might block the gutter should be taken into account in northern climates - a larger gutter might be needed. Lap joints in the gutter must allow for lengthwise thermal expansion and contraction while remaining watertight. Watertight lap joints are particularly important for valley gutters, in which a leak will result in expensive water damage to the building's interior. Lap joints can be eliminated if the gutter is formed of one continuous length of metal, but the thermal expansion and contraction of such a long section can cause problems if the gutter is fastened rigidly to the roof panels or substrate along its entire length. In cold weather, condensation can form on the interior (building) side of a valley gutter when humid indoor air contacts the gutter's cold surface. Some manufacturers provide features to catch the condensation so it does not drip on the building contents.

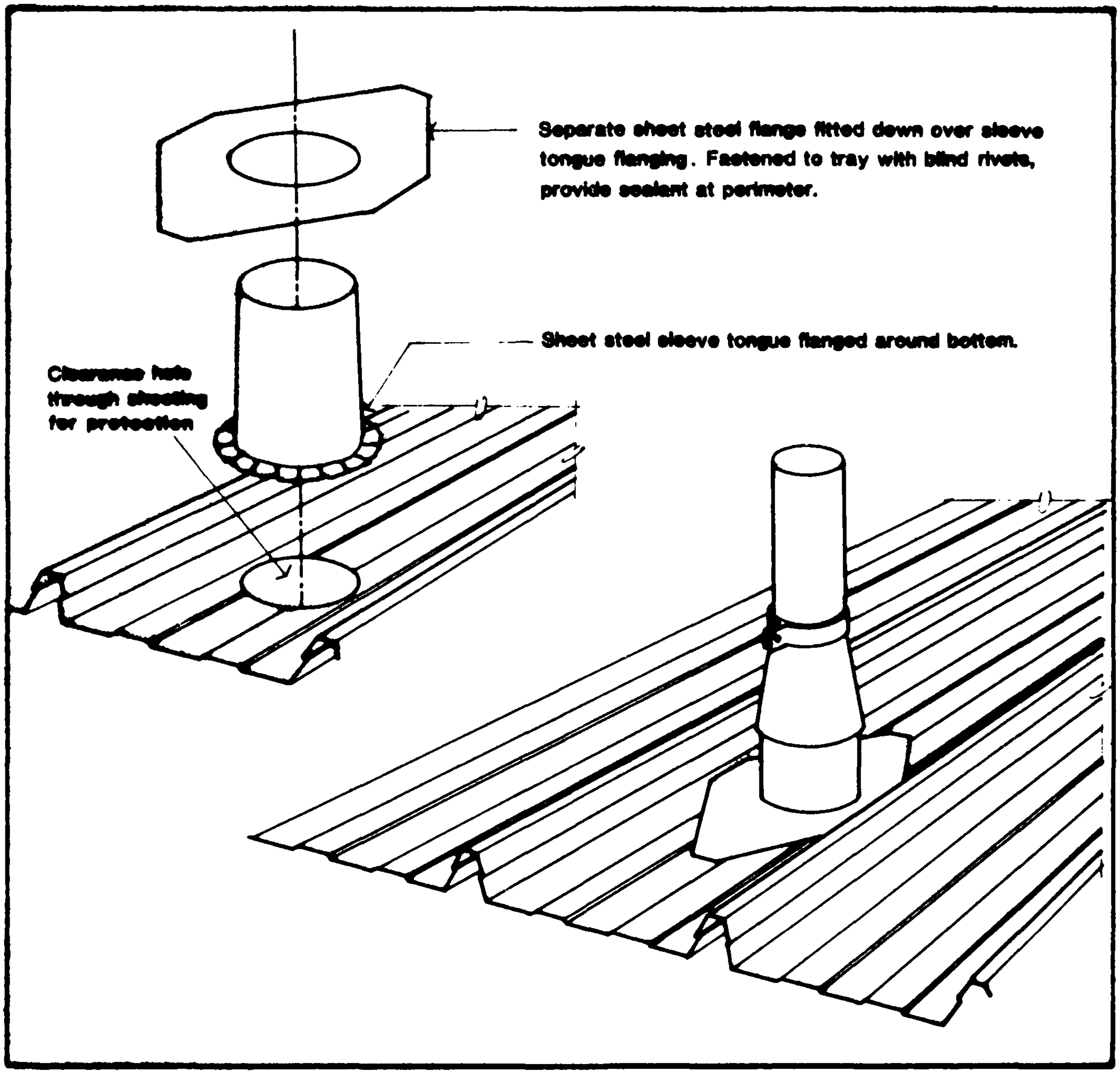
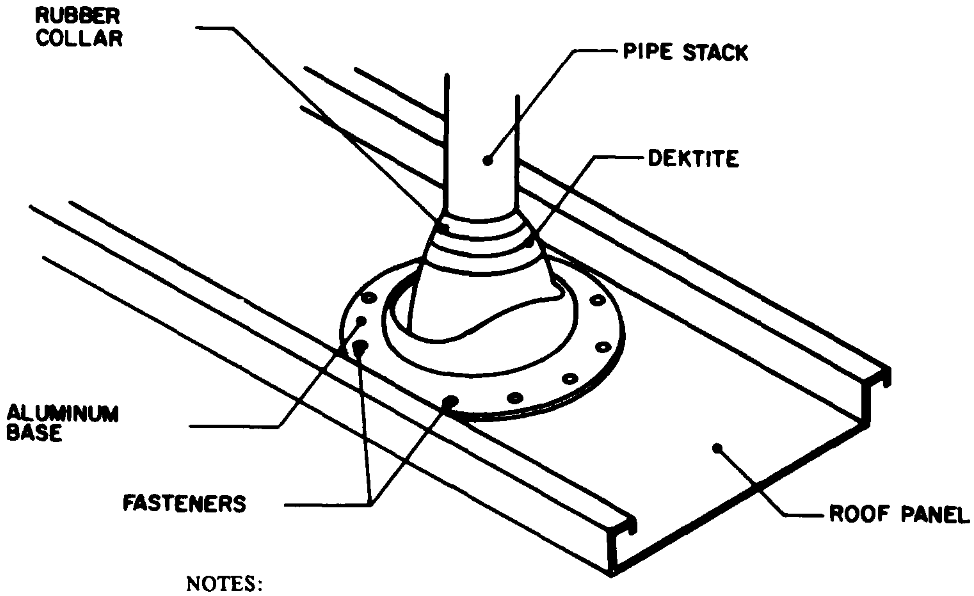


Figure 15. Sheet steel pipe flashing away from panel rib.



NOTES:

1. Roof jack accommodates pipe sizes 3" thru 11" o.d. Jack is tapered cone, to be field cut to pipe or stack size.
2. Base is made of corrosion resistant aluminum.
3. Rubber collar is EPDM, compounded with carbon black and other additives. Life expectancy is in excess of 30 years.
4. Color is black with aluminum base.

Figure 16. Rubber gasketed pipe flashing away from panel rib.

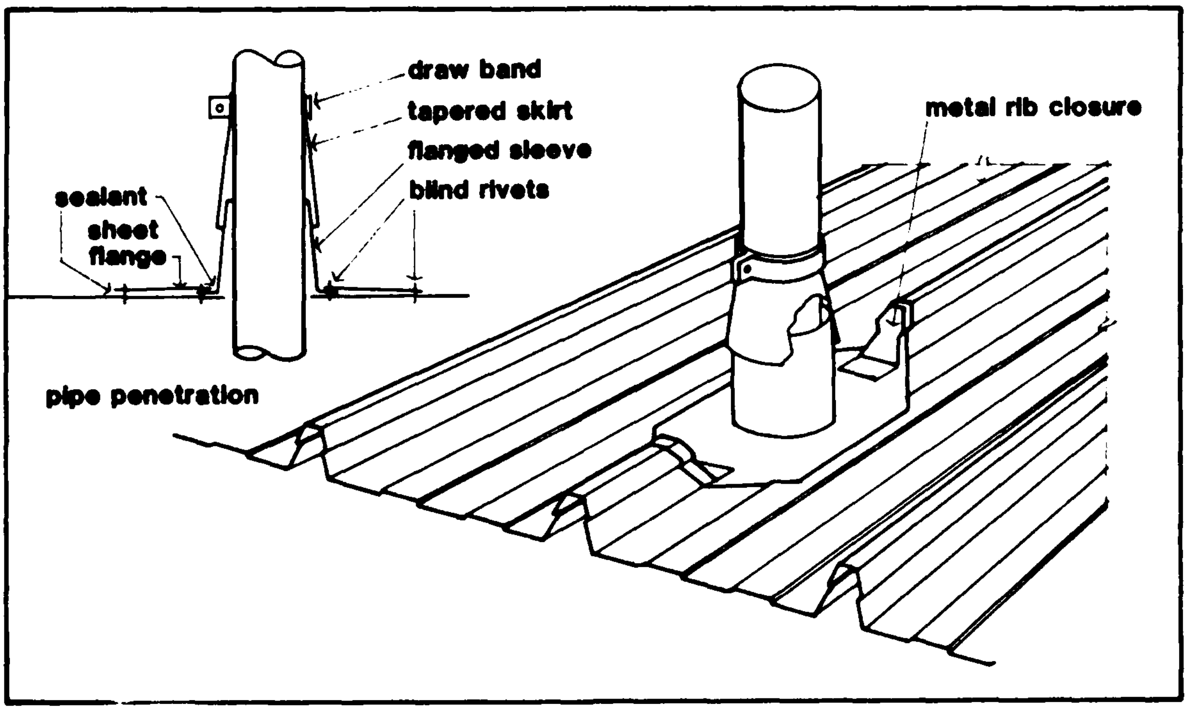


Figure 17. Sheet metal pipe flashing at panel rib.

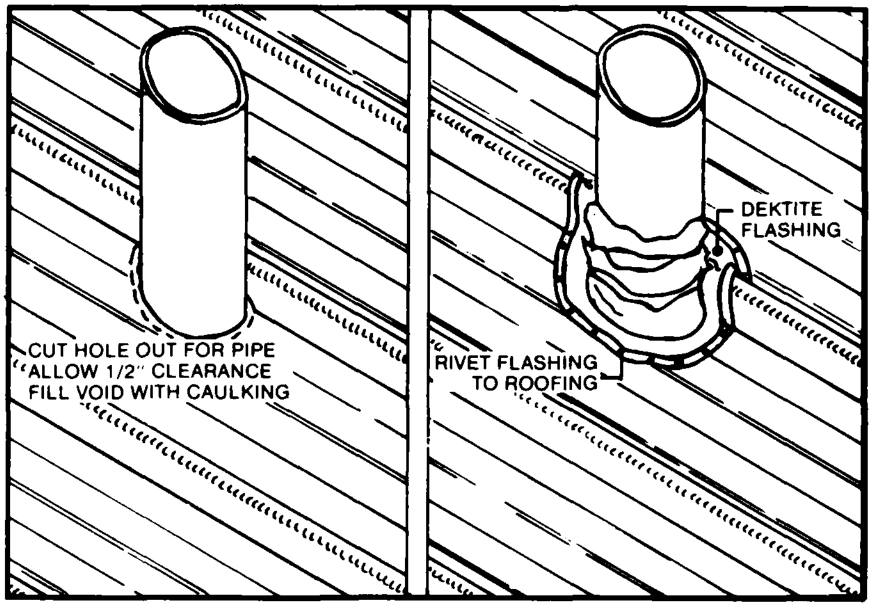


Figure 18. Rubber gasketed pipe flashing at panel rib.

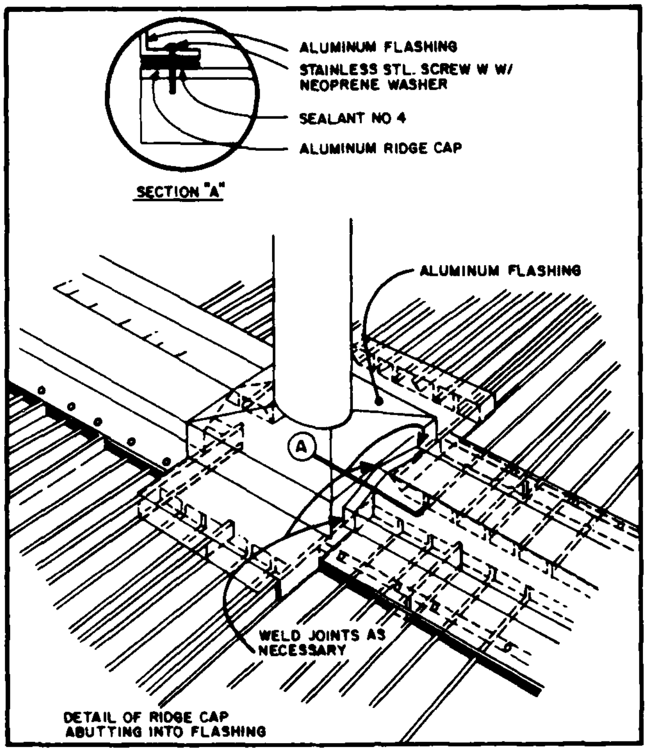
1. *Parapet Valley Gutter With Condensation Pan.* The condensation pan catches moisture as it drips off the gutter; however, unless some sort of drain is provided, the moisture must evaporate from the condensation pan (Figure 23). The gutter is well supported from below to handle foot traffic. No insulation is shown below the gutter; thus, building heat would tend to melt any ice or snow that might block the gutter and interfere with drainage. Connection between the gutter and parapet is with a flexible (EPDM) membrane that allows for differential thermal movement between the two parts. Connection between the gutter and roof substrate on the other side is indirect enough to allow some differential thermal movement. The gutter lap joint design is not shown in Figure 23. (Armco Building Systems)

2. *Parapet Valley Gutter With Secondary Gutter.* The secondary gutter might provide enough insulation to prevent building heat from melting snow and ice in the primary gutter. This design could allow standing water in the gutter or on the roof (Figure 24). Double void closures in the roof panel ends form a tight seal. The secondary gutter acts as a condensation pan for the first gutter. Thermal movement of the secondary gutter would be small because this gutter would not be subjected to the temperature extremes of the primary gutter; thus, the fact that the secondary gutter is fastened ridigly to both the parapet and a roof joist is not a problem. The connection between the primary gutter and the structural joist is indirect enough to allow thermal movement of the primary gutter on that side without buckling. The primary gutter is fastened rigidly to the parapet wall and could distort with thermal movement if it is made of one continuous length of material. If the primary gutter is in short lengths (10 to 12 ft), thermal movement is no problem, but lap joint design becomes critical. (Vulcraft/Nucor Corp.)

3. *Parapet Valley Gutter.* This gutter is fastened rigidly to the parapet and is connected directly to the roof substrate (Figure 25); the design is acceptable if the gutter is in sections no longer than 10 to 12 ft (to accommodate thermal movement). The gutter's lap joint design is an important detail that has been omitted in Figure 25, and no feature is shown to handle the problem of condensation on the gutter's underside. Building heat would tend to melt ice and snow that might otherwise block the gutter and allow leaks into the building. (American Buildings Co.)

4. *Valley Gutter–Roof-to-Roof Junction.* As Figure 26 shows, no device has been included to handle condensation on the gutter's underside. An uninsulated gutter means the building would tend to melt ice and snow that might otherwise block the gutter and allow leaks into the building. If the gutter is one continuous

(a)



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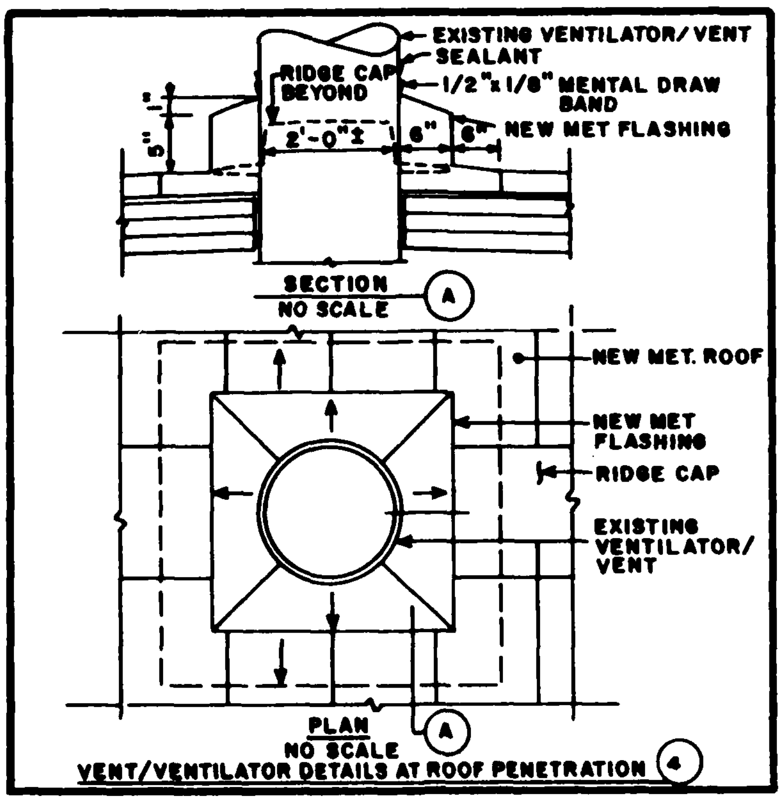


Figure 19. (a and b) Two views of pipe flashing at ridge cap.

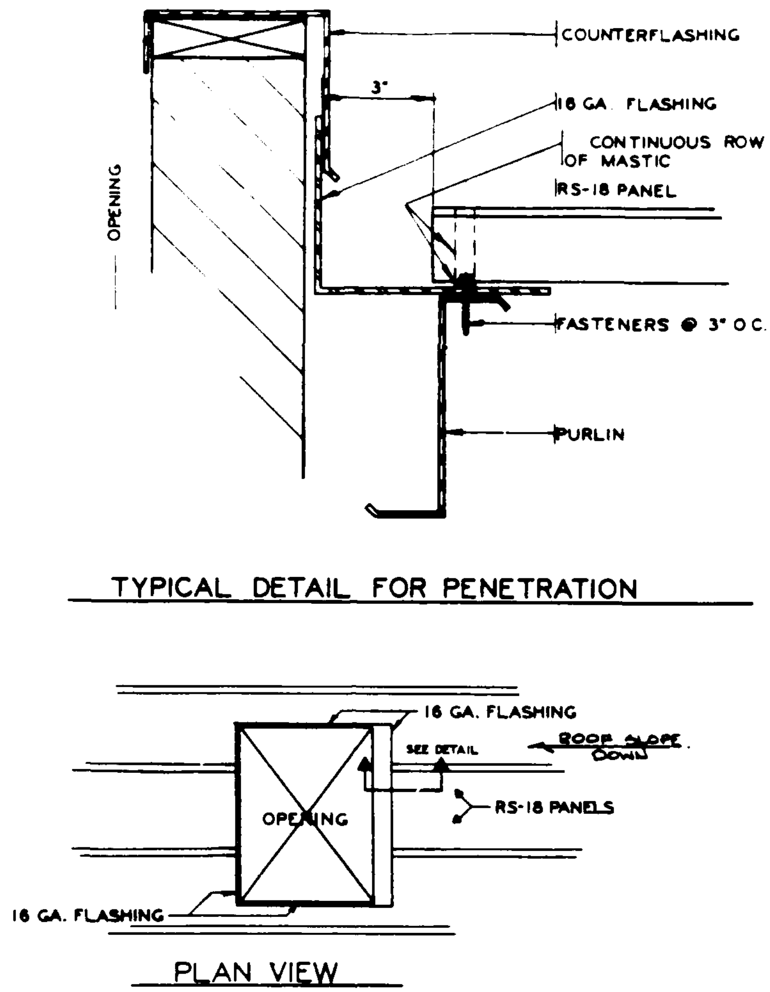


Figure 20. Curbed opening without diverter.

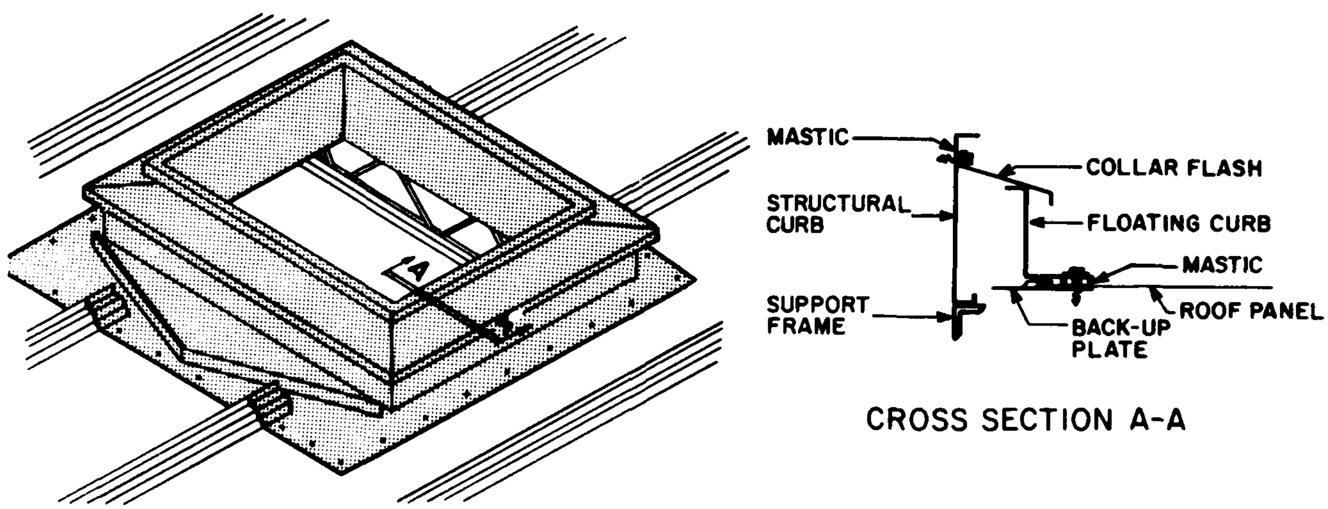


Figure 21. Curbed opening with diverter water directed to either side of curb.

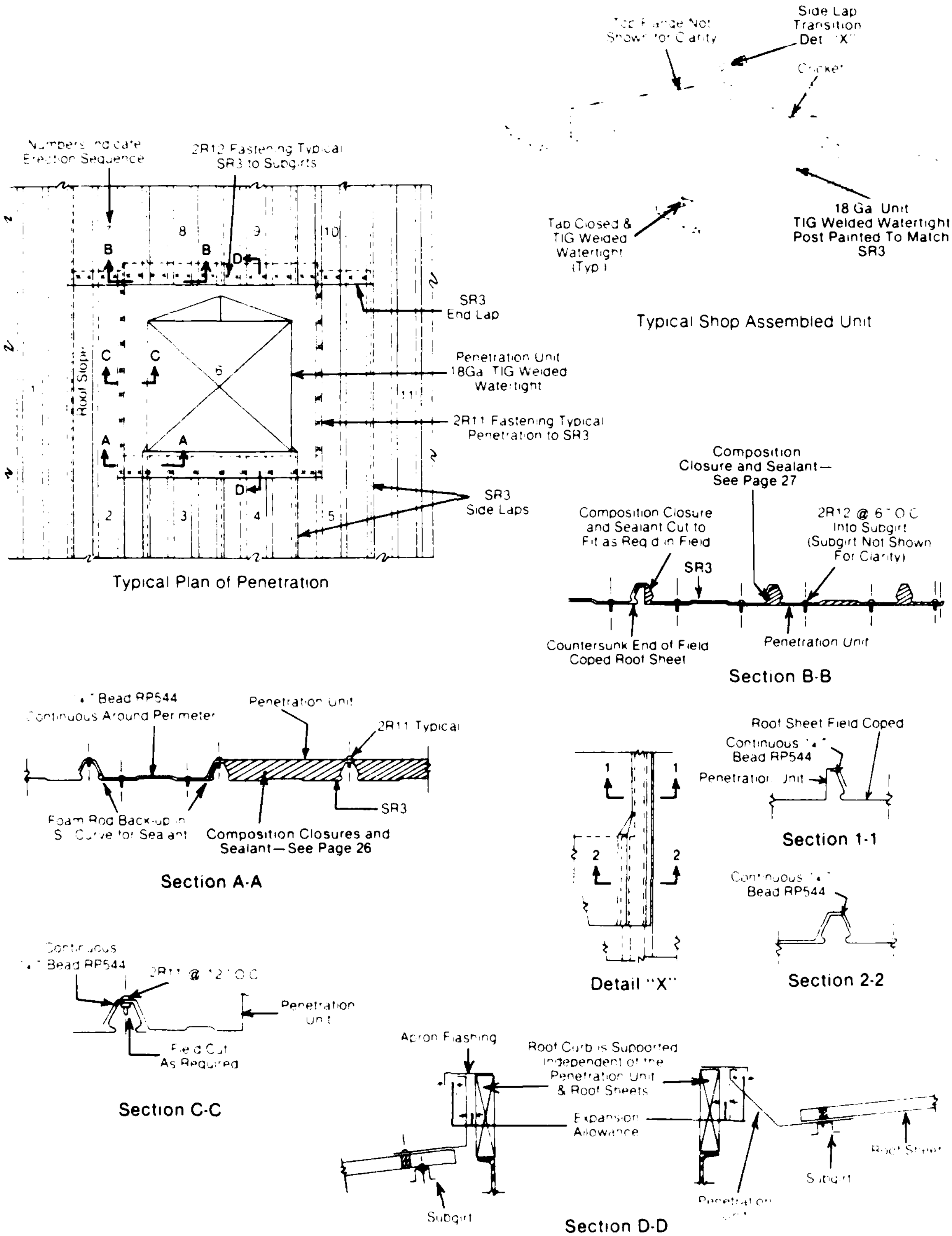


Figure 22. Curbed opening with diverter water directed around curb.

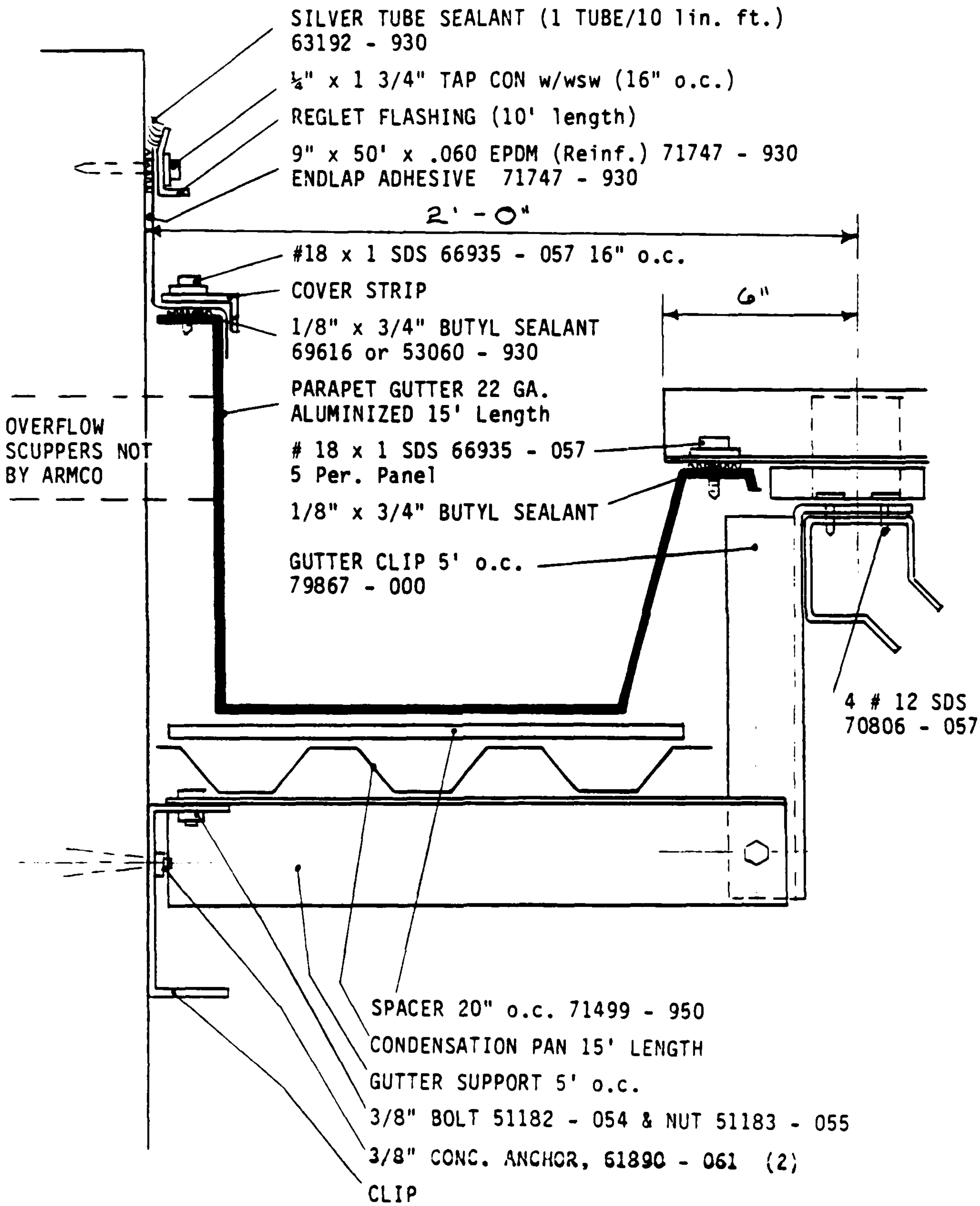


Figure 23. Parapet valley gutter with condensation pan.

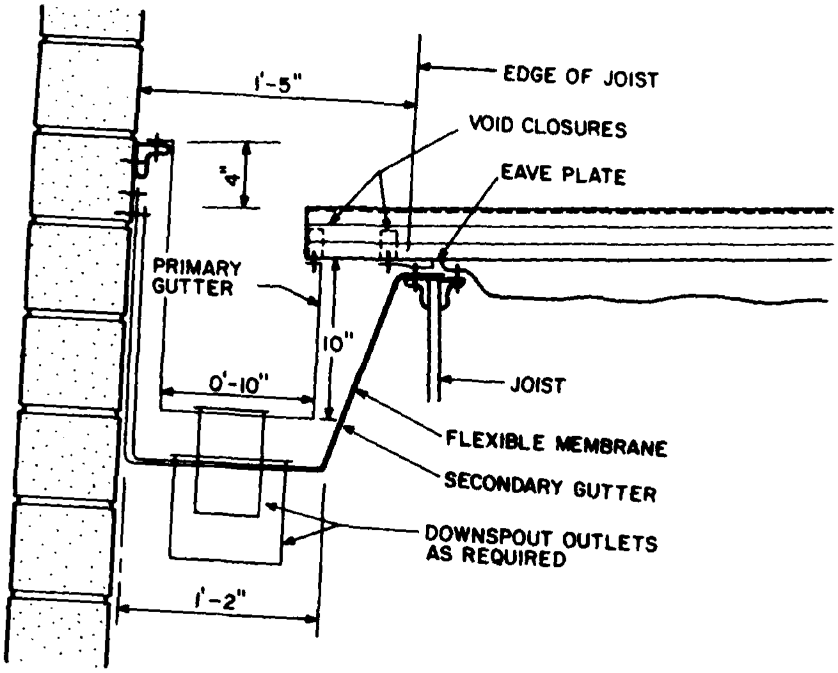


Figure 24. Parapet valley gutter with secondary gutter

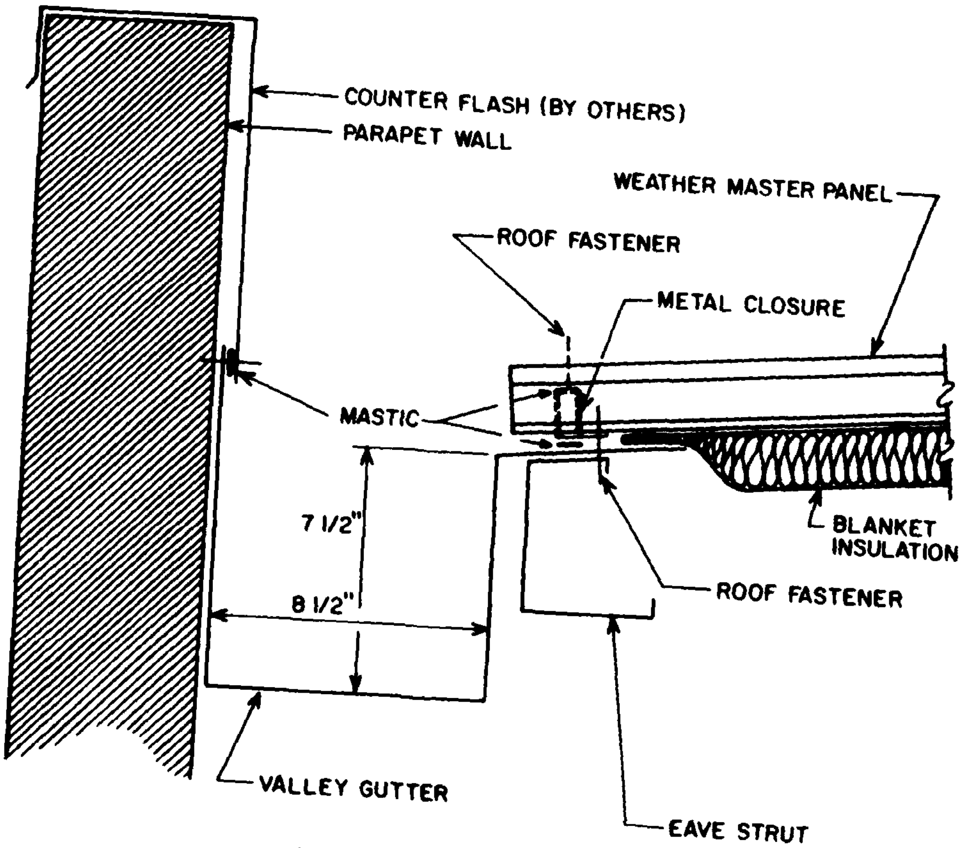


Figure 25. Parapet valley gutter.

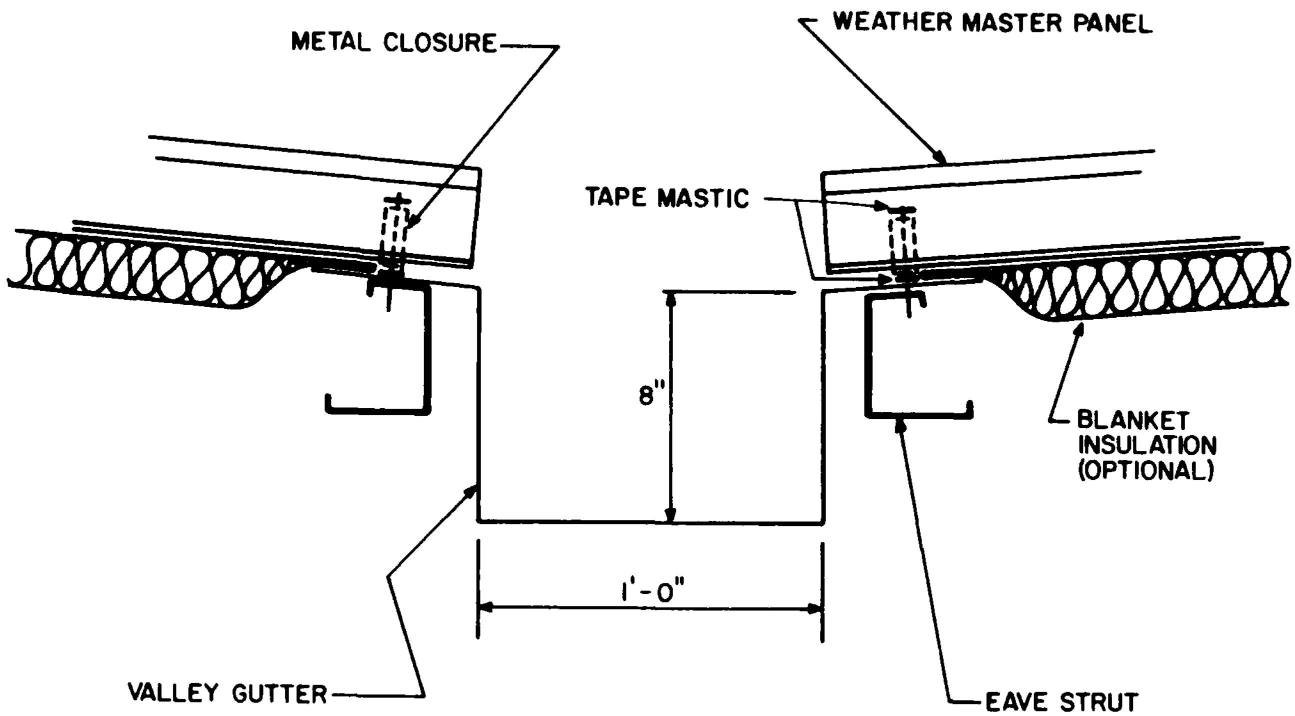


Figure 26. Valley gutter - roof-to-roof juncture.

length, thermal movement in relation to the eave struts might cause the gutter to buckle. If the gutter is formed of 10- to 12-ft sections, thermal movement of each section would be manageable but gutter lap joints would become a critical detail. (American Buildings Co.)

5. *Valley Gutter Roof-to-Roof Junction and Secondary Gutter.* The secondary gutter might provide enough insulation to prevent building heat from melting snow and ice in the primary gutter; this design could result in standing water in the gutter or on the roof (Figure 27). Double-void closures in the roof panel ends form a tight seal. The secondary gutter acts as a condensation pan for the primary gutter. Thermal movement of the secondary gutter would be small because this gutter would not be subjected to the temperature extremes of the primary gutter; thus, the fact that the secondary gutter is fastened rigidly to the roof joists is not a problem. The connection between the primary gutter and the structural joists is indirect enough to allow thermal movement of the primary gutter without buckling. If the primary gutter is in short lengths (10 to 12 ft), thermal movement would be no problem, but lap joint design would become critical. (Vulcraft, Nucor Corp.)

6. *Deep Valley Gutter.* The optional condensation pan should be used since it would catch moisture dripping off the gutter; however, unless some sort of drain is included, the moisture must evaporate from the condensation pan (Figure 28). The gutter is well supported from below to handle foot traffic. No insulation is shown below the gutter detail in Figure 28, meaning building heat would tend to melt any ice or snow that might block the gutter and interfere with drainage. Connection between the gutter and roof substrate is indirect enough to allow some differential thermal movement. Figure 28 does not show the gutter's lap joint design. (Armco Building Systems)

7. *Built-in Gutter Example 1.* This gutter is attached to a solid substrate (Figure 29). The sealant under the drip caps must be effective when snow and ice or debris in the gutter causes water to back up. If the caulking fails, standing water could climb between the drip cap and the C-closure by capillary action and wet the substrate. Also, the starter strip's design encourages water entry under the roofing panels. Figure 29 does not show the gutter lap joint detail, but this feature is important because leaks would damage the substrate and possibly the building contents. (ACS Pacific, Inc.)

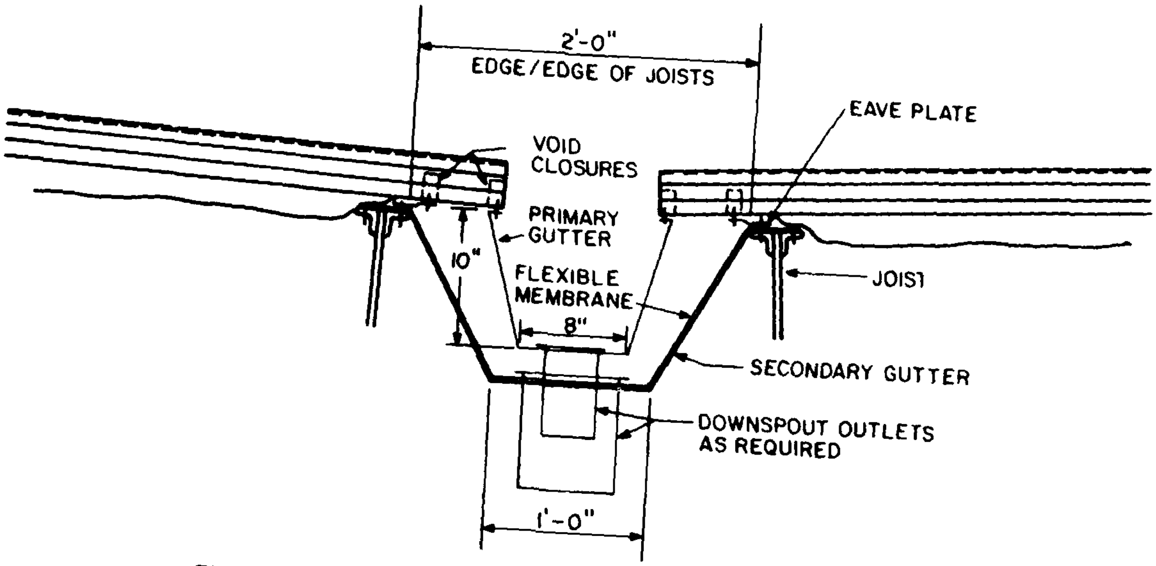


Figure 27. Valley gutter - roof-to-roof juncture and secondary gutter.

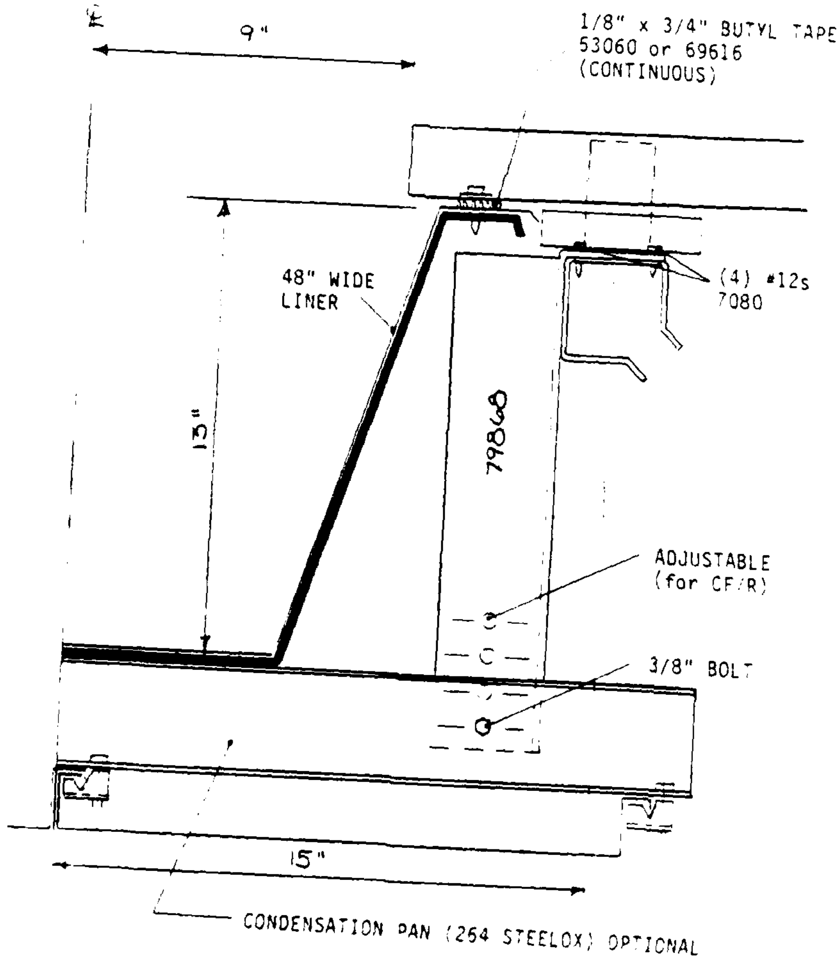


Figure 28. Deep valley gutter.

8. *Built-in Gutter Example 2.* This gutter is attached to a solid substrate (Figure 30). The joggle cleat is a much better method of securing the end of the panel than that of example 1 (above). If no sealant is used, standing water due to a blocked gutter could climb between the drip and the gutter by capillary action and wet the substrate. Figure 30 does not show the gutter lap joint detail, but this feature is important because leaks would damage the substrate and possibly the building contents. (AEP SPAN)

9. *Eave Gutter Example 1.* This gutter's overflow would cause little or no trouble, since it would empty outside the buidling (Figure 31). Fasteners that support the gutter penetrate roof panels outside the building wall. Longitudinal thermal movement of the gutter in relation to roof panels would be a problem if the gutter is one continuous piece; however, there should be no problem if the gutter is in 10- to 12-ft lengths. The design of watertight gutter lap joints is not as critical as for an interior valley gutter. (Roof Systems, Inc.)

10. *Eave Gutter Example 2.* This gutter is structurally isolated from the roof panels and has its own independent support; thermal movement can be accommodated independently (Figure 32). If the gutter were blocked and water backed up, the overflow would spill outside the building. Fasteners for the drip flashing penetrate the panel only at the very edge, where leaks drain into the gutter. (H. H. Robertson Co.)

Hips

A hip occurs at the intersection of two sloped roof surfaces and runs from the ridge to the eave the eave end being at an exterior corner of the building. A hip often is treated similar to a ridge; the main difference is that the roof panels are not perpendicular to the line of the hip. This design may not accommodate thermal expansion and contraction of the different elements. Hips are used on residential or small commercial roofs more often than on large, industrial roofs.

1. *Notched Hip Cap.* This hip is similar to a ridge. A 1-in. gap is left at the hip for thermal expansion of roof panels (Figure 33). Assuming the roof panels are fixed at the eave, very little thermal movement will occur in the shorter panels at the low end of the hip. The longer panels at the high end of the hip will have the most thermal movement. Figure 33 gives no indication of how the panels are supported at the hip; the regular roof purlins are neither parallel nor perpendicular to the hip. The hip flashing is notched to fit over the ribs of the roof panel. If this flashing is one continuous length, the notches could interfere with its lengthwise thermal expansion and contraction. (Rib-Roof Industries)

2. *Hip Flashing With Hipster.* This hip also is similar to a ridge (Figure 34). The panels cannot have longitudinal thermal movement at the hip; thus, movement must be allowed at the eave. Alignment of ribs at the hip joint could be difficult to maintain. Misalignment would affect the flashing and hipster cap fit. Rib alignment is impossible unless the two roof surfaces are at the same slope. Panels are screwed to solid blocking under the hip to ensure adequate support. Fasteners through the flashing strip could be a source of leaks unless care is taken in applying a sealant. In general, this detail is unobtrusive and clean in appearance. (Rib-Roof Industries)

Panel End Laps

These terminations are used when the roof slope is too long to be covered by one continuous length of roof panel. Some manufacturers specify that end laps be staggered on adjacent rows of panels so that the number of extra plies of metal in the side lap seam is minimized. In addition, one of the panels can be factory-trimmed to reduce the extra plies. Other manufacturers specify that end laps be aligned on adjacent rows of panels, rather than staggered. In this situation, one or more panel edges are usually trimmed and/or swaged at the factory to provide a smooth fit in the side lap seam. On purlin-supported roofs, the end lap can occur either over a purlin (where the purlin can provide support) or away from the purlins. When an end lap occurs over a purlin, the fasteners often are driven into the purlin to draw the connection tight; consequently, the roof panels cannot move due to thermal expansion and contraction at that point. This condition must be kept in mind and the panels should be allowed to "float" at both the eave and the ridge to avoid buckling. The main concern when a lap joint occurs away from a purlin is whether the lap joint is strong enough to support occasional foot traffic.

1. *Lap Joint Fixed at Purlin.* Lap joint fasteners are driven into a purlin (Figure 35); thus, the lap joint is a fixed point and thermal expansion and contraction of the roof panels must be accommodated at both the eave and the ridge. The lower panel is notched at the factory so that the seam cap does not have to wrap around extra plies of metal. If the lap joints are not staggered on successive panel runs, the vertical portion of the seam will have two extra thicknesses of metal

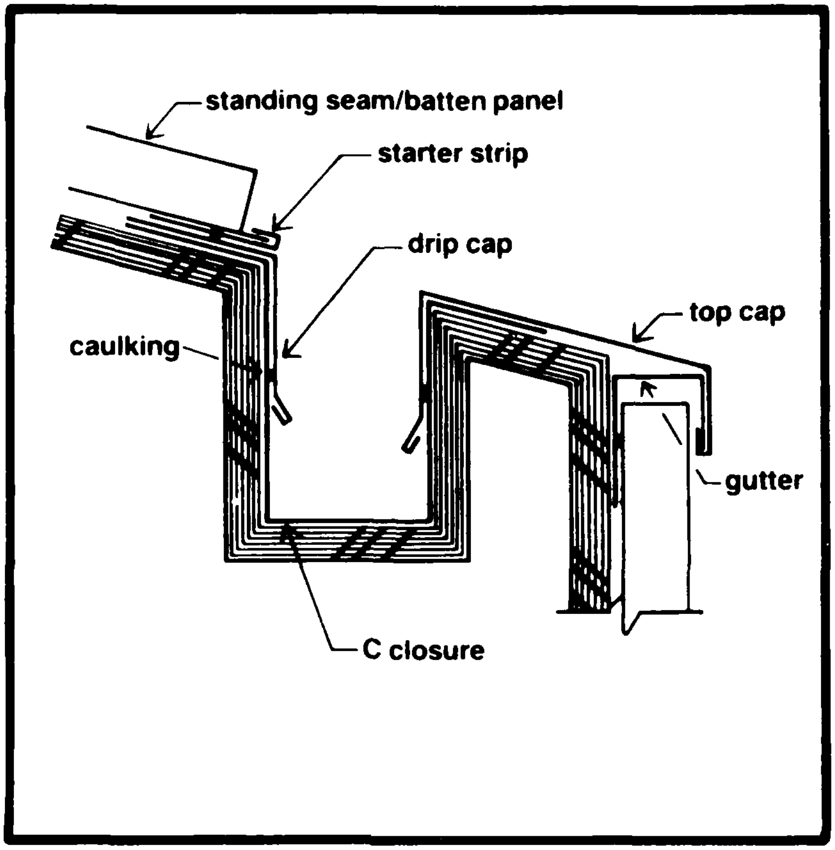


Figure 29. Built-in gutter example 1

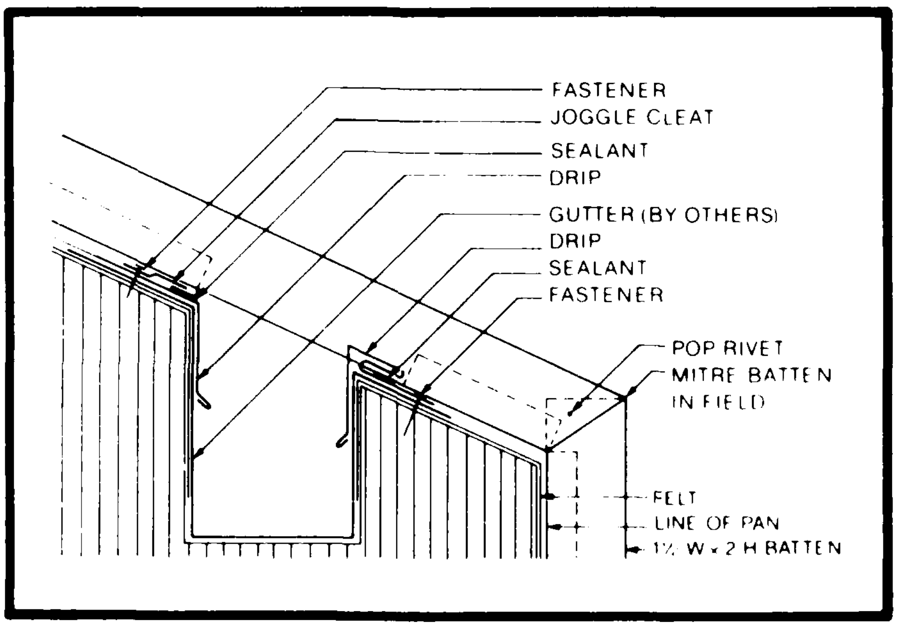


Figure 30. Built-in gutter example 2.

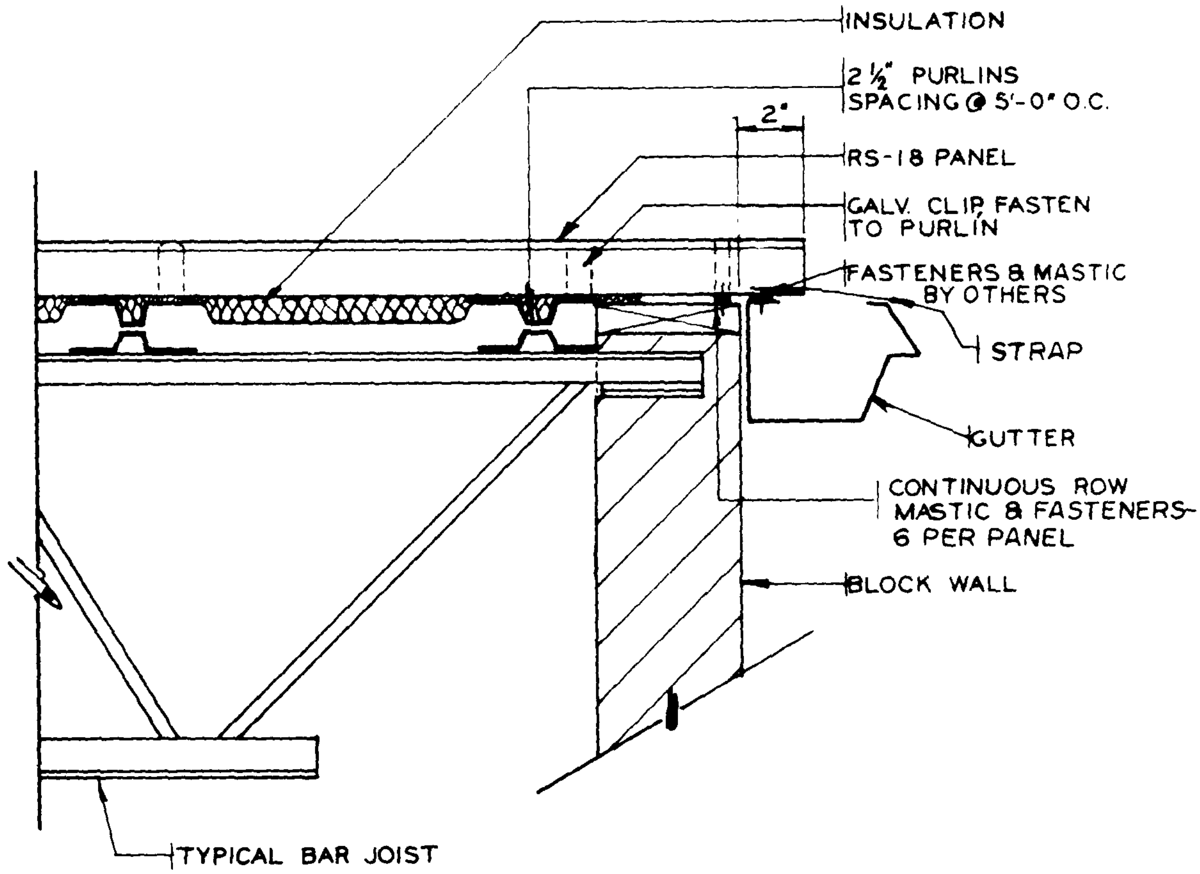


Figure 31. Eave gutter example 1.

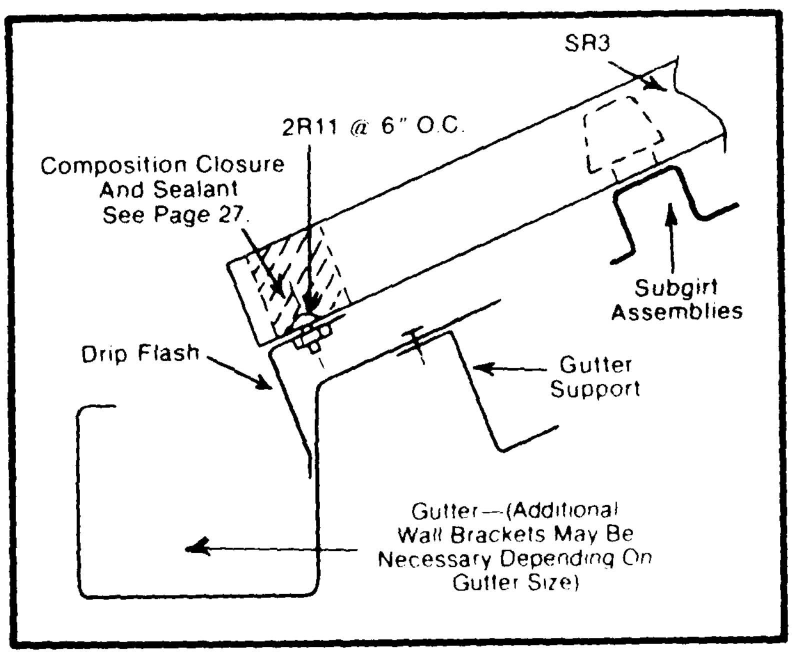


Figure 32. Eave gutter example 2.

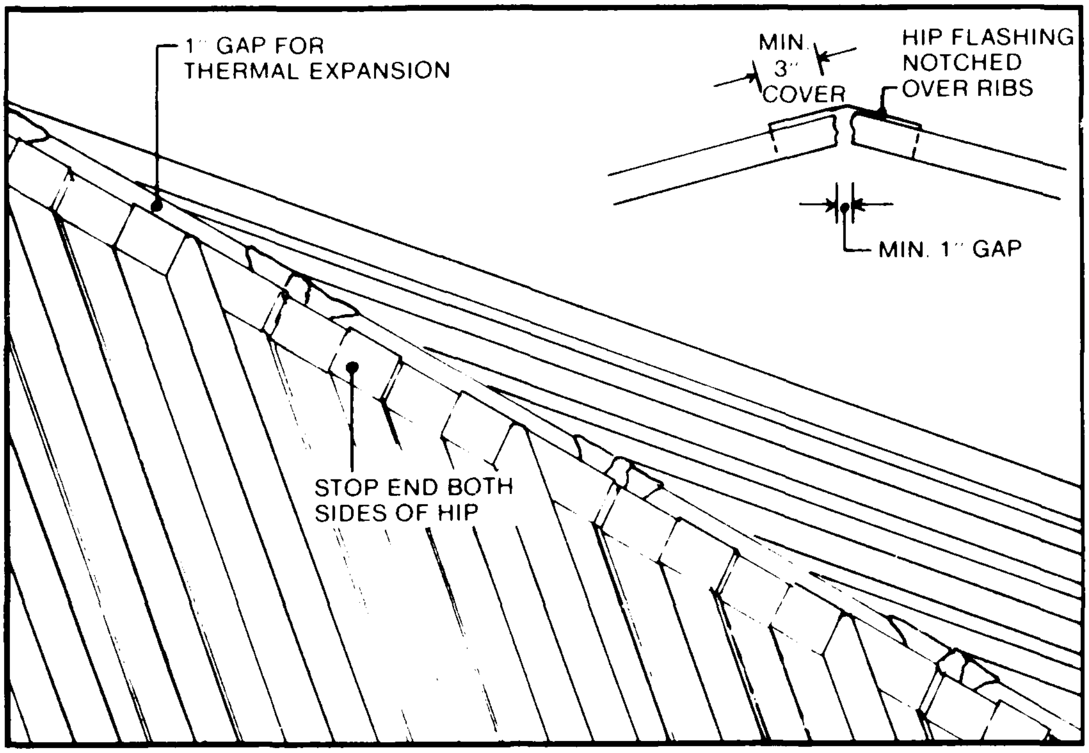


Figure 33. Notched hip cap.

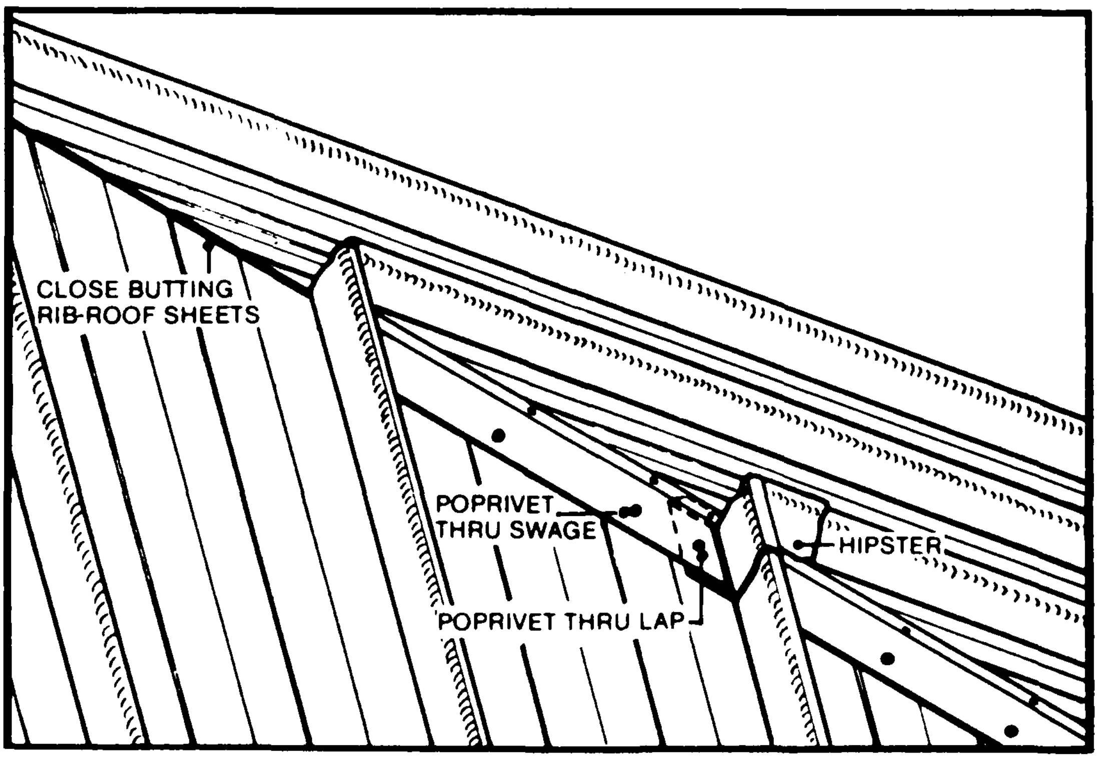


Figure 34. Hip flashing with hipster.

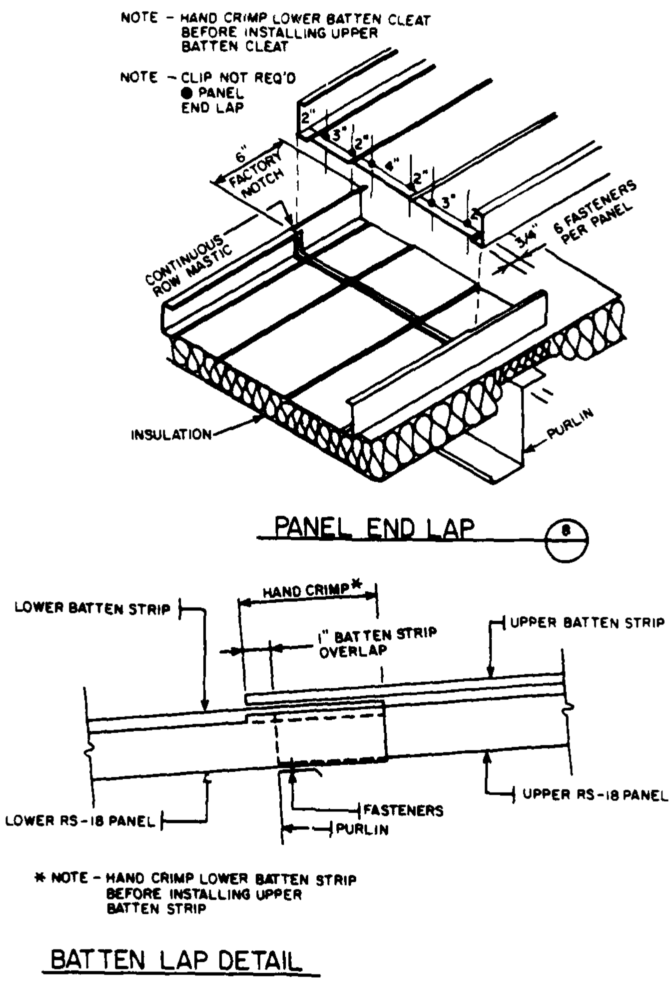


Figure 35. Lap joint fixed at purlin.

rather than just one. (This situation should not cause problems, though.) Mastic must be applied accurately so that it seals around the lap fasteners as they are driven through the panels. (Roof Systems, Inc.)

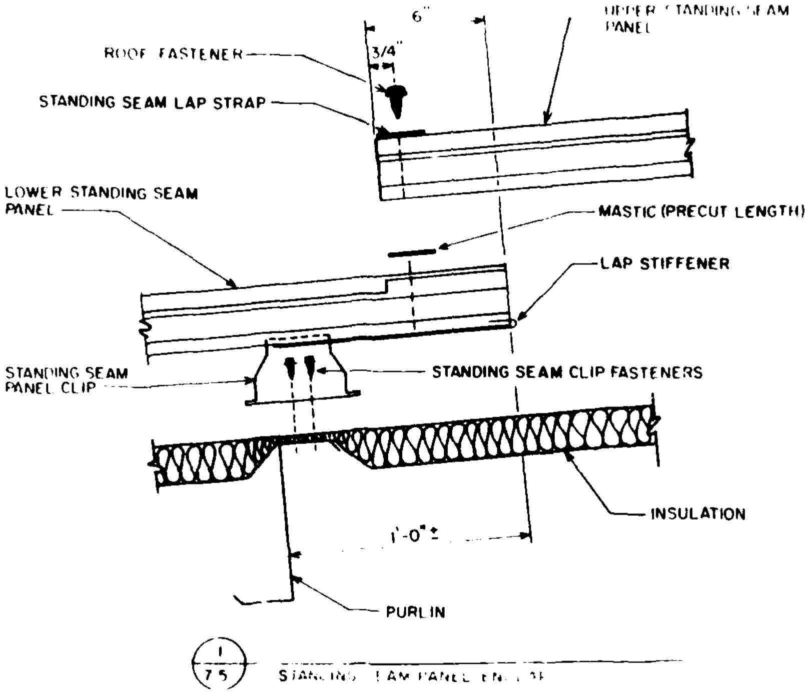
2. *Floating Lap Joint With Stiffener Strap.* This lap joint is made close to a purlin so that the purlin provides some support (Figure 36). However, the lap is structurally independent of the purlin to allow thermal movement of the roofing panels. Placing the lap strap on top and the lap stiffener below distributes fastener forces for a better seal and allows foot traffic on the lap joint. Mastic is site-applied, but is wide enough so that slight inaccuracies in its application will not affect the seal. The lower panel is notched and the end laps are staggered so there are no extra plies of metal in the seam. (American Buildings Co.)

Profile Closures

Profile closures are needed with certain panel profiles to seal between the roofing panel and the substrate at the eave line (see Figure 61 in Chapter 5). In addition, many types of roofing panels require profile closures at the ridge to provide a flat surface against which the ridge cap can seal. Profile closures are commonly made of Neoprene, metal-clad Neoprene, or stamped sheet metal.

1. *Metal-Clad Neoprene Closure.* Metal cladding provides protection for the Neoprene and keeps it in position (Figure 37). In addition, the metal cover keeps even pressure on the Neoprene and provides a flat surface against which the ridge cap can seal. Neoprene will cure in place to the exact shape required. (Architectural Manufacturing, Inc./Architectural Panels, Inc.)

(a)



(b)

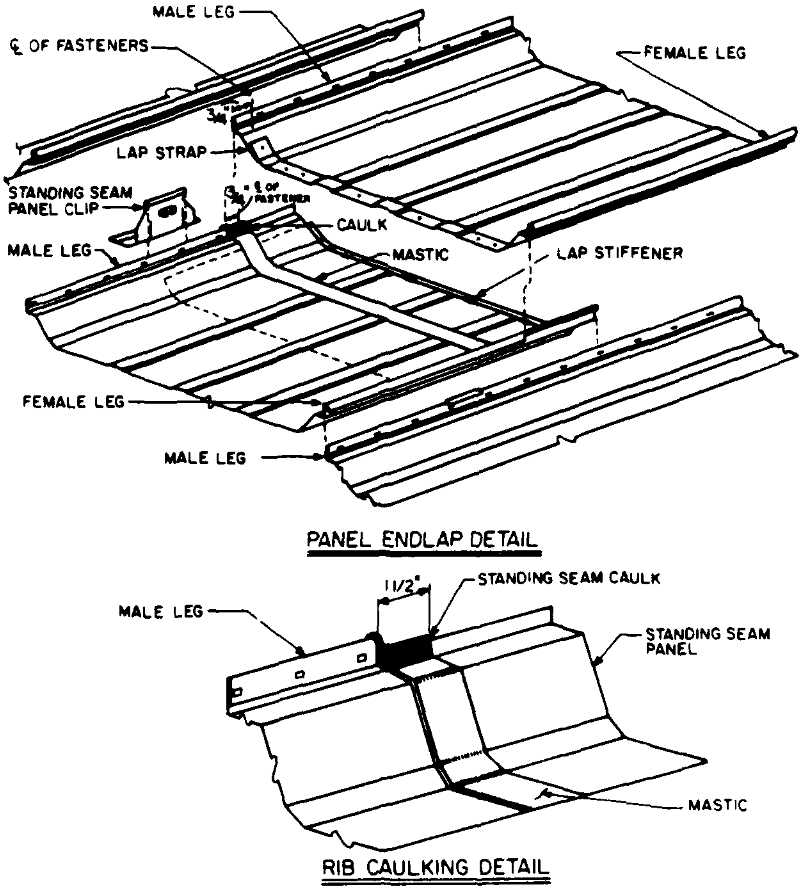


Figure 36. (a and b) Two views of floating lap joint with stiffener.

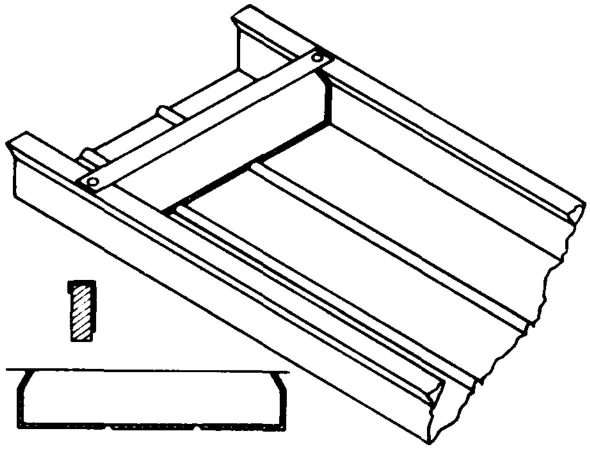


Figure 37. Metal-clad Neoprene profile closure.

2. *Metal Closure With Tape Mastic*. This detail (Figure 38) might work better if the lower strip of tape mastic were applied to the bottom of the metal closure before the closure is attached to the panel, rather than trying to lay the tape mastic on the panel in the correct location with no guideline. The method suggested by the manufacturer might result in misalignment of the mastic and the metal closure piece. (American Buildings Co.)

3. *Josbsite-Prepared Box End*. This procedure involves minor trimming at the jobside. The box end is waterproof if it is used with the proper cap flashing. The manufacturer states that the peak end of all panels should be prepared in this way before starting the roof sheeting (Figure 39). On large jobs, it might be more practical to prepare the peak ends in groups of 10 or 20 as required, rather than to have hundreds of prepared panels getting in the way. (Dean Steel Buildings, Inc.)

Ridges

A ridge is the high horizontal line formed by the intersection of opposite slopes of a roof. Two basic approaches deal with ridges on metal-roofed structures. The first six details below show what can be called the "low-profile approach," in which the ridge becomes a smooth transition between opposite slopes of the roof. The low-profile treatment generally requires the roof panels to be fixed at the ridge and allowed to float at the eaves. Ridge ventilation is more difficult with a low-profile ridge than with the higher profile type. In details 7 through 10, the ridge is a more obvious feature on the roof. Longitudinal thermal movement of the roof panels at the ridge can be readily accommodated with this type of detail. The final detail shows the addition of a round ridge vent to the higher profile ridge.

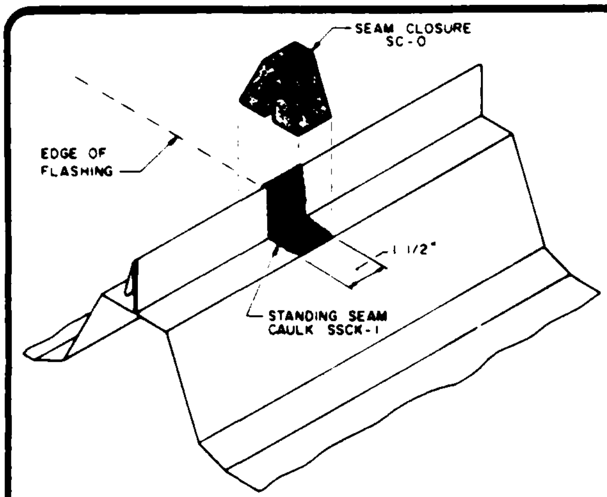
1. *Continuous Ridge*. Panels should be fixed at the ridge purlins and eave ends of the panels should be allowed to float (Figure 40). The ridge bend probably is made in the shop rather than at the jobsite, which could make those panels more difficult and expensive to ship. The end laps are staggered and one panel is trimmed back to eliminate extra plies of metal in the seam. It is difficult to see (from Figure 40) how a ridge vent could be accommodated in this detail. (Fabral/Alcan Building Products)

2. *Cut Rib With Rib Cap*. Roof panels in this ridge do not appear to be fastened to the ridge purlin; panels could buckle upward at the ridge if this is true (Figure 41). Repeated cycles of buckling could cause the rib cap seal to fail. Panels should be attached firmly to the ridge purlin and allowed to float at the eave. The rib cut must be located accurately because that determines where the panels bend. The rib cap must be able to handle a variety of different slopes. Adequate caulking beneath rib cap is critical. (Rib-Roof Industries)

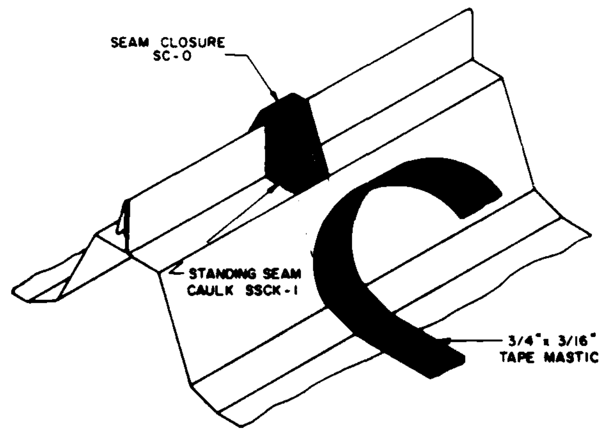
3. *Riveted Ridge Flashing With Spire*. Roof panels are screwed to the ridge purlin; thus, panels must be allowed to float at the eaves (Figure 42). More exposed fasteners mean more chances for leakage than with detail 2 (above). The spire must be adjustable to fit a variety of roof slopes. Adequate sealant beneath the pan flashing and spire is critical. (Rib-Roof Industries)

4. *Shop-Formed Ridge Panel*. Roof panels are fixed at the ridge purlins; thus, panels must be allowed to float at the eaves (Figure 43). The lap joints are not staggered on adjacent panels. Even though the edge of one panel is trimmed back, there will still be one extra ply of metal in the seam, which could produce a poor seal. (Epic Metals Corp.)

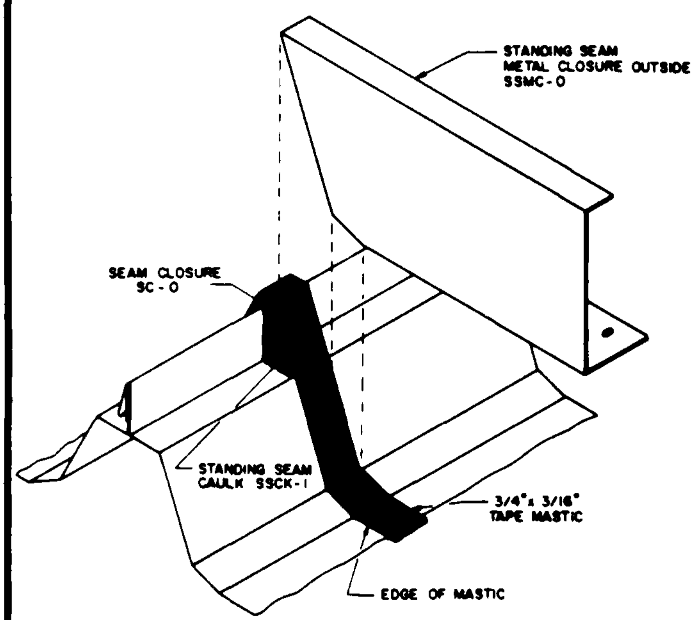
5. *Field-Cut Ridge Panel*. These roof panels are fixed at the ridge purlins; thus, panels must be allowed to float at the eaves. The roof panel is trimmed where it meets the ridge section so the seam cap does not have an extra ply of metal to enclose (Figure 44). Lap joints are not staggered; the vertical portion of the seam contains two extra plies of metal. However, this design probably will have no problems because of the seaming method. It may be difficult to seal the rib cut properly at the ridge. (Roof Systems, Inc.)



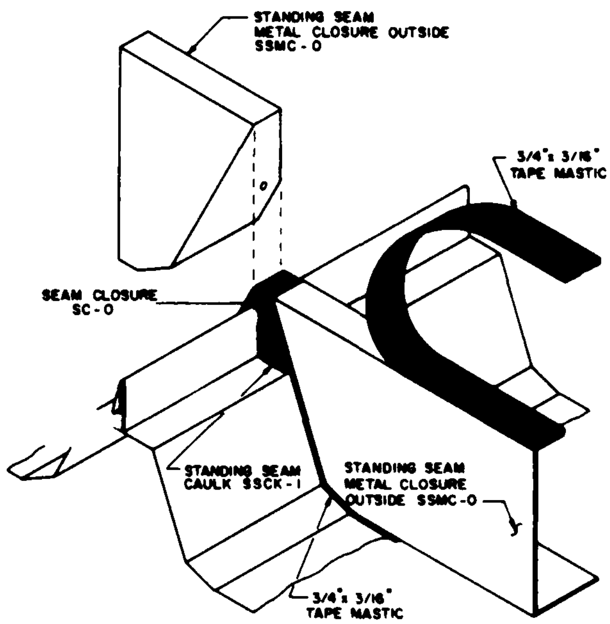
STEP 1. INSTALL CAULK SSCK-1 ON BOTH SIDES OF SEAM AS SHOWN ABOVE. POSITION SEAM CLOSURE, SC-O, OVER CAULKED SEAM AND PRESS FIRMLY IN PLACE.



STEP 2. INSTALL 3/4 x 3/16 TAPE MASTIC ACROSS PANEL FLAT AND OVER RIB AND CLOSURE. KEEP RUN OF MASTIC INTACT FOR PLACEMENT ON NEXT PANEL.



STEP 3. INSTALL METAL OUTSIDE CLOSURE FLUSH WITH EDGE OF MASTIC. SECURE IN PLACE WITH 6 HEX HEAD FASTENERS THROUGH PREPUNCHED HOLES.

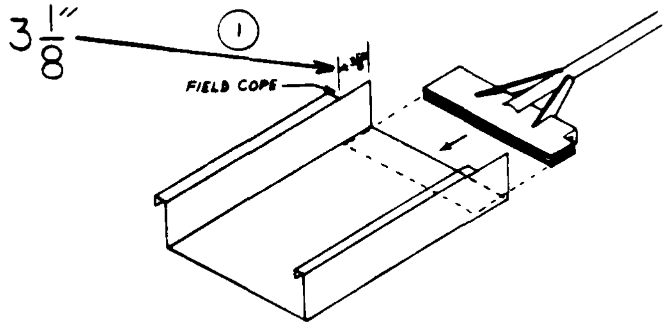


STEP 4. REPEAT WITH ADDITIONAL CLOSURES FOR FULL LENGTH OF FLASHING INSTALLATION. COMPLETE DETAIL BY RUNNING 3/4" x 3/16" TAPE MASTIC ALONG TOP EDGE OF CLOSURE.

Figure 38. Metal closure with tape mastic.

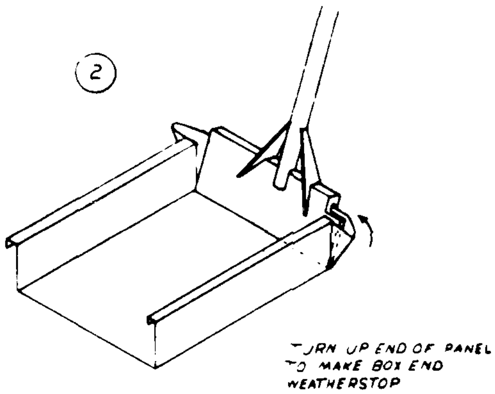
WEATHERSTOP BOX END

THE PEAK END OF ALL PANELS SHOULD HAVE THE WEATHER STOP BOX END DETAIL COMPLETED BEFORE STARTING THE ROOF SHEETING.

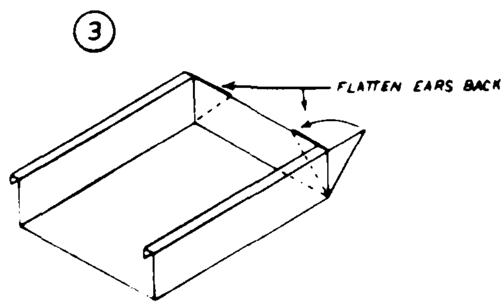


ERECTOR NOTE:
BEND THE COPED ENDS OUTWARD PRIOR TO MAKING THE 90° BEND. THIS WILL ALLOW THE MATERIAL TO MOVE OUTWARD.

STEP 1: FIELD COPE THE PANEL BACK $3\frac{1}{8}$" FROM THE END.



STEP 2: INSERT THE END BENDING TOOL & FOLD THE PANEL UPWARD. THE EXTRA SIDE MATERIAL WILL FOLD OUTWARD. BEND UNTIL 90 DEGREE BEND IS ACHIEVED.



STEP 3: ONCE THE END BEND IS COMPLETED, FOLD THE EXCESS SIDE MATERIAL AROUND TO THE BACK OF THE BOX - NEVER TO THE SIDES. BY FOLDING TO THE BACK, IT WILL LOCK THE END BOX INTO PLACE.

Figure 39. Jobsite-prepared box end.

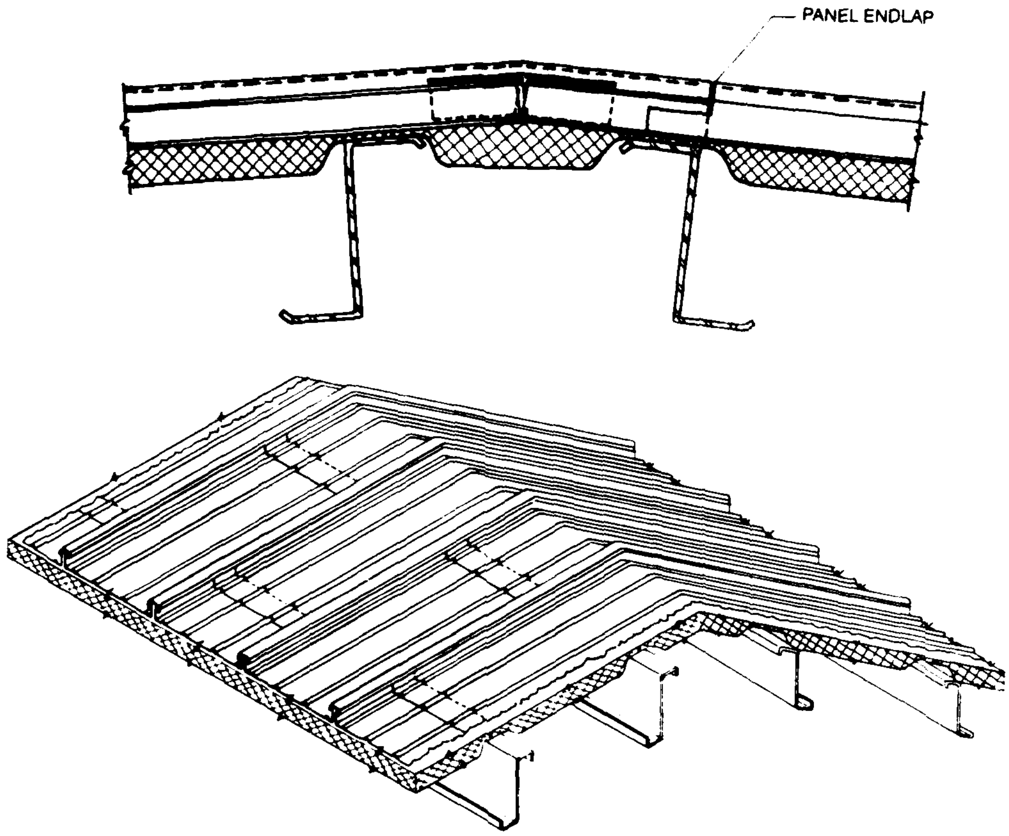


Figure 40. Continuous ridge.

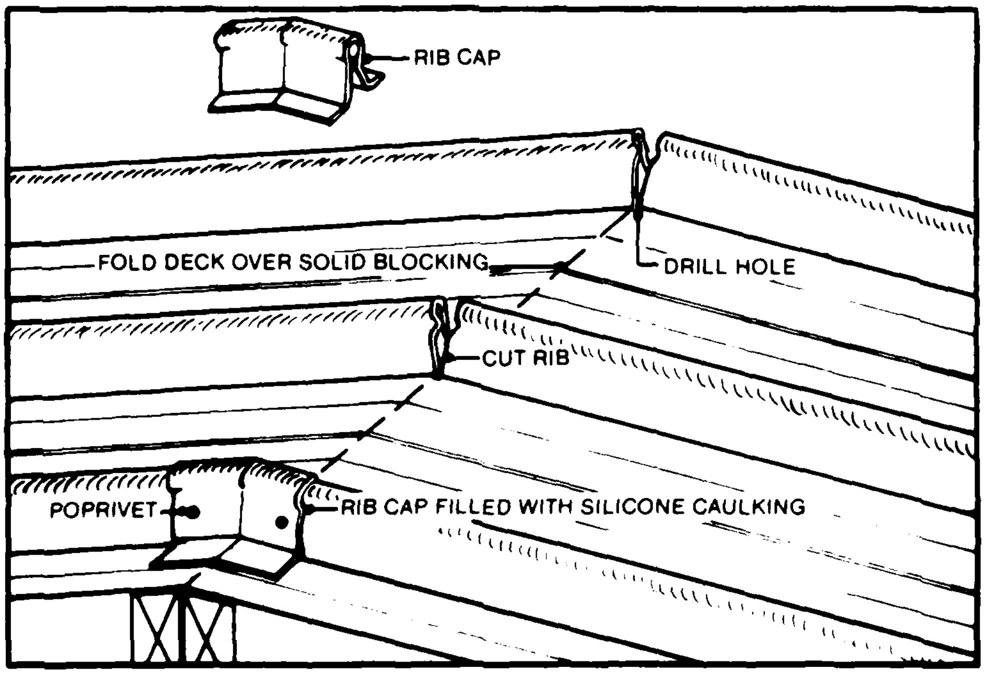


Figure 41. Cut rib with rib cap.

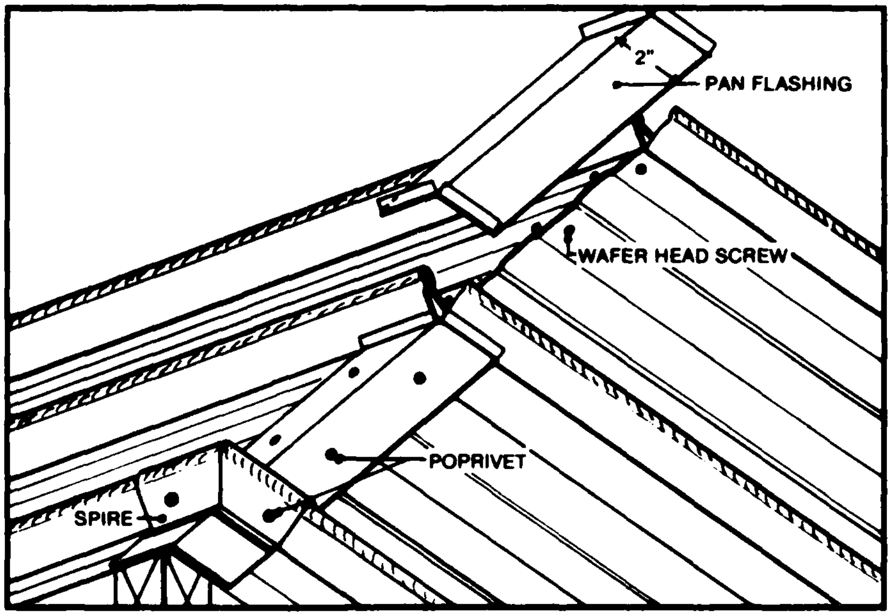


Figure 42. Riveted ridge flashing with spire.

6. *Field-Bent Ridge Panel.* These roof panels should be fixed at the ridge purlins (Figure 45); thus, problems could occur if adjacent panels are allowed to move relative to one another near the ridge bend. There also could be some difficulty creating the ridge bend at the proper location on each panel (assuming the bend is created at the jobsite). (Roof Systems, Inc.)

7. *Ridge Cap With Profile Closures–Example 1.* Two different types of ridge caps are available, depending on whether roof panels are fixed or allowed to float longitudinally at the ridge. The ridge cap should be attached in lengths of no more than 10 to 12 ft because of its longitudinal thermal expansion and contraction. Extra support is provided under the ridge cap to handle foot traffic and other heavy loads (Figure 46). A profile closure is required to create the seal between the roof panels and the ridge cap. The numerous through fasteners required to hold down the ridge cap create opportunities for leaks to form. (Metal Building Components, Inc.)

8. *Ridge Cap With Profile Closures–Example 2.* The design of this ridge cap does not allow for longitudinal movement of the roof panels at the ridge (Figure 47). Fasteners for the ridge cap are 12 in. on-center; spacing probably should be less for a good seal between the profile closure and the ridge cap. The ridge cap should be attached in lengths of no more than 10 to 12 ft because of its longitudinal thermal expansion and contraction. (American Buildings Co.)

9. *Ridge Cap With Profile Closures–Example 3.* This ridge cap is designed to allow longitudinal thermal expansion and contraction of the roof panels at the ridge (Figure 48). The ridge cap should be attached in lengths of no more than 10 to 12 ft because it also undergoes longitudinal thermal expansion and contraction. A profile closure is required to create the seal between the ridge cap and the roof panels. (Vulcraft/Nucor Corp.)

10. *Circular Ridge Vent.* This ventilator flashing design does not allow for longitudinal thermal expansion and contraction of the roof panels at the ridge (Figure 49). Fasteners for the ventilator flashing are 12 in. on-center; spacing should probably be less for a good seal between the flashing and the roof panel profile closure. (American Buildings Co.)

Roof-Wall Flashing

A roof-wall flashing is needed whenever a wall rises above the roof surface (e.g., at a parapet or fire separation wall). Two different situations can occur: (1) the roof meets the wall at the edge of the slope (i.e., the wall runs parallel to the slope) or (2) the roof meets the wall at the high end of the slope (i.e., the wall runs perpendicular to the slope). In the first case,

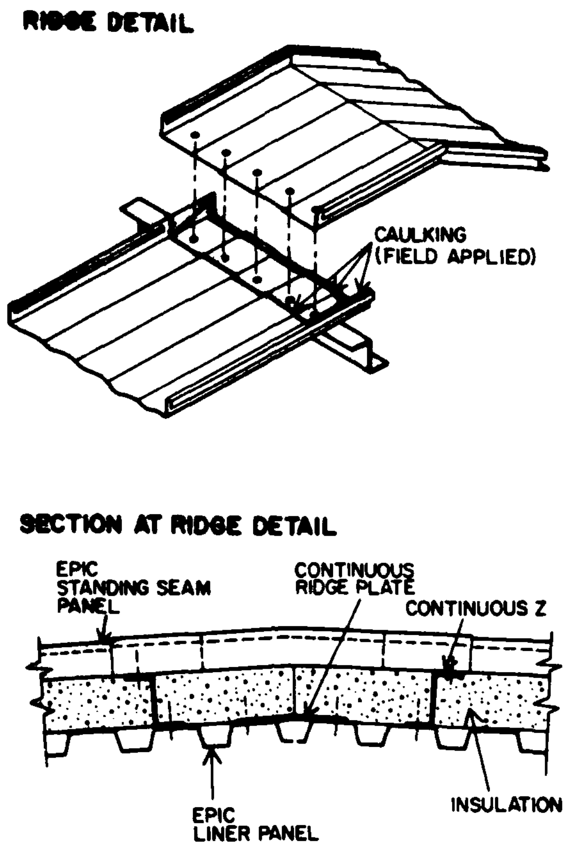


Figure 43. Shop-formed ridge panel.

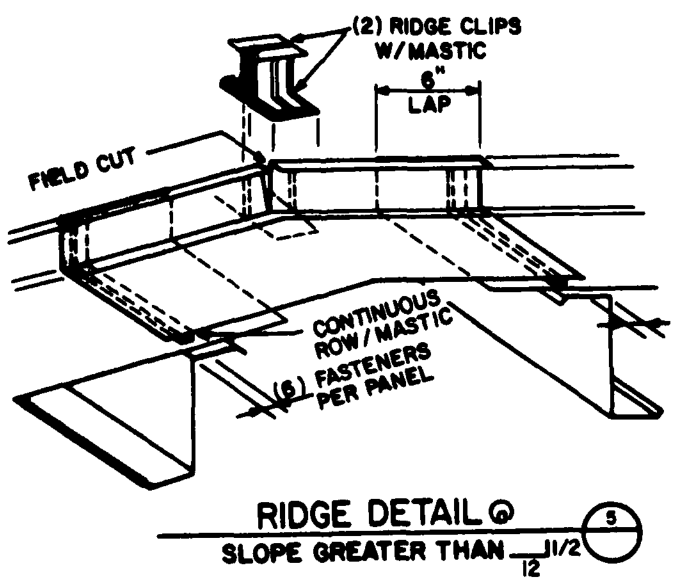


Figure 44. Field-cut ridge panel.

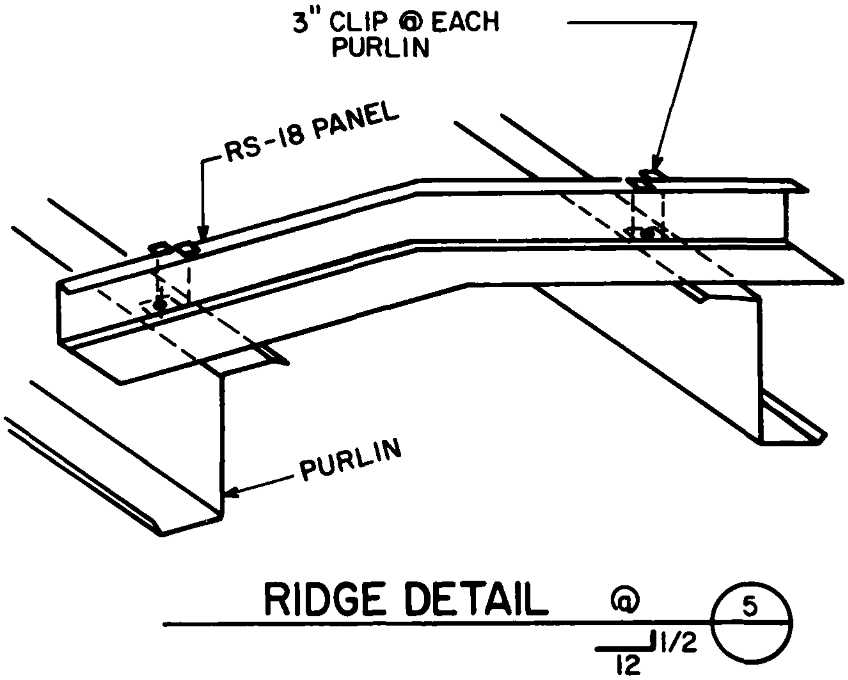


Figure 45. Field-bent ridge panel.

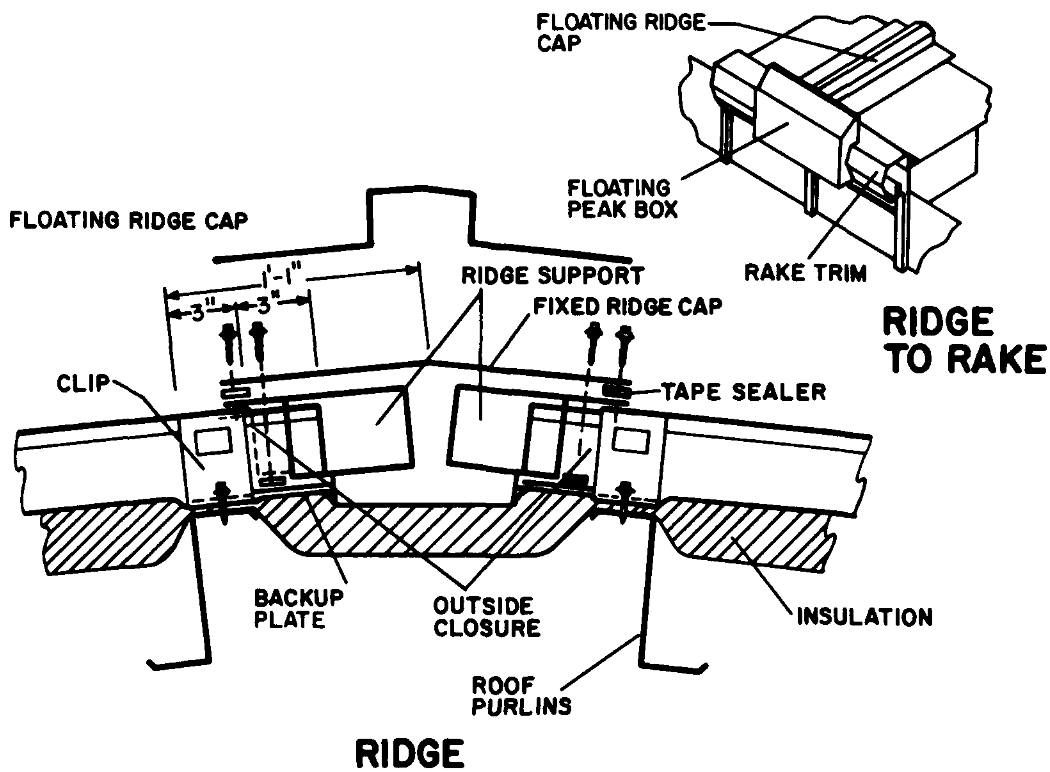


Figure 46. Ridge cap with profile closures example 1.

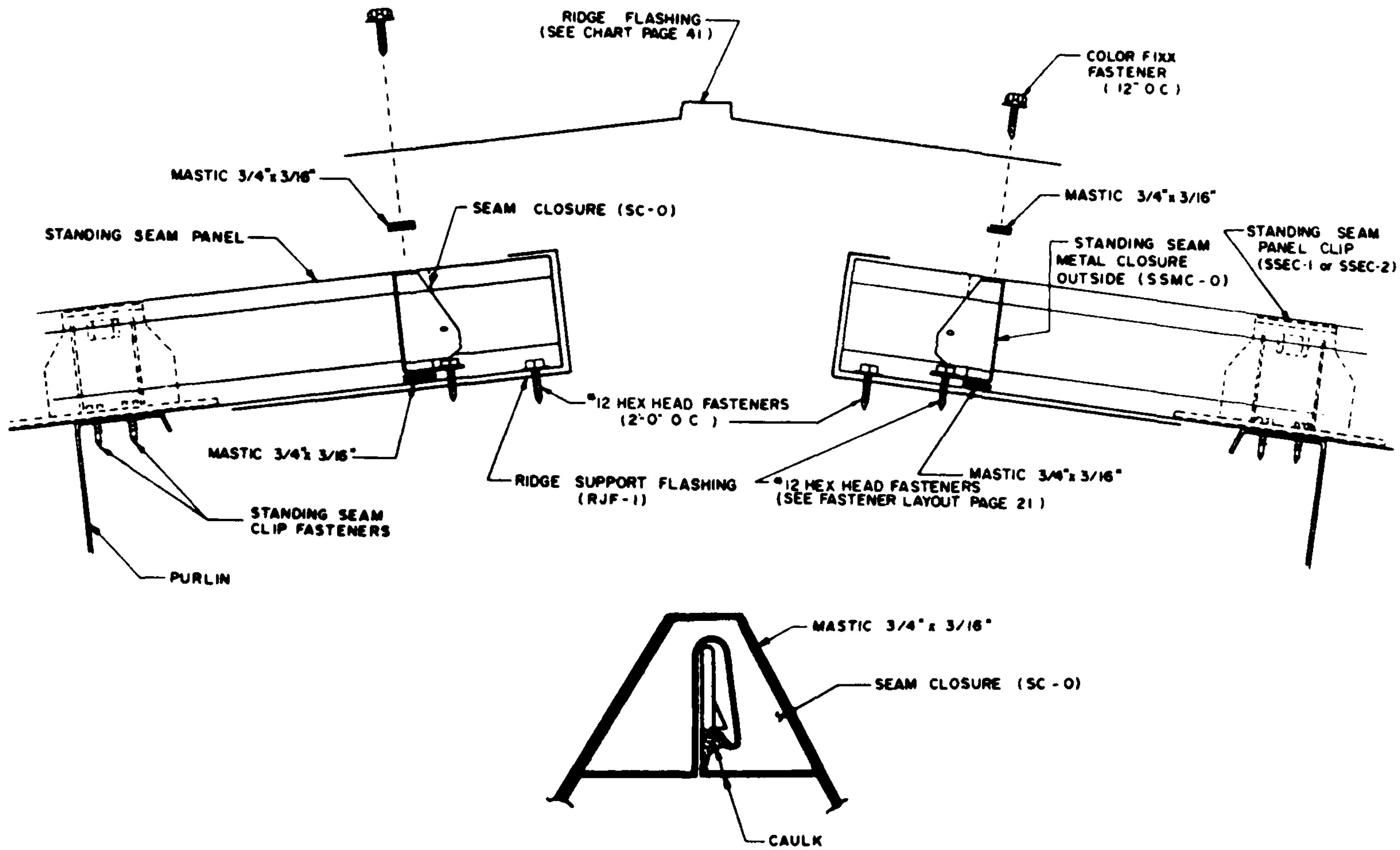


Figure 47. Ridge cap with profile closures—example 2.

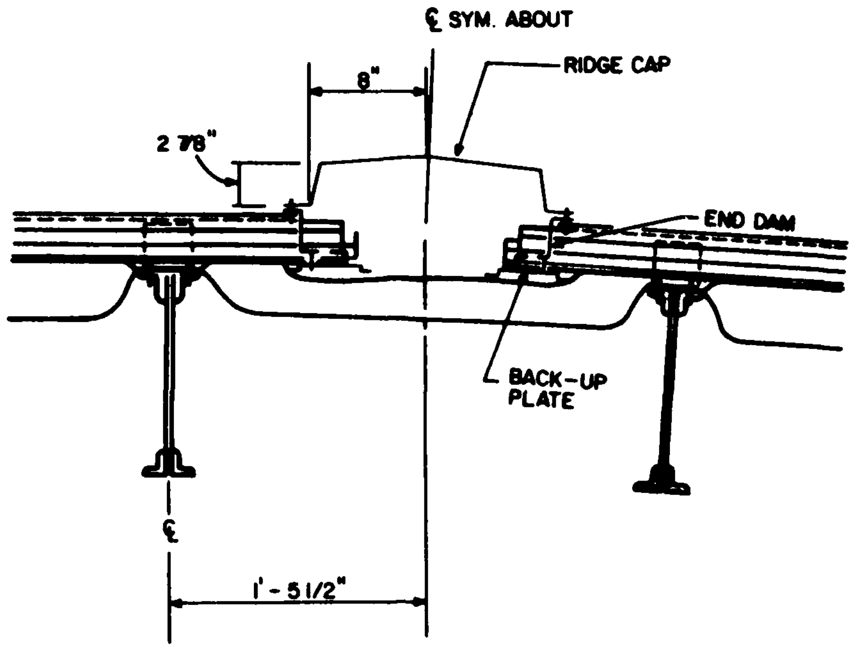


Figure 48. Ridge cap with profile closures—example 3.

depending on how the flashing is constructed and installed, there may or may not be relative movement between the roof panel and the flashing as a result of thermal expansion and contraction. Two different ways of dealing with the second case are to have the roof panels fixed or free to move longitudinally at the high end of the slope. If the roof panels are free to move (or "float") at the high end, the flashing must be flexible enough to allow that movement. If the roof panels are fixed at the high end, the flashing is less complicated. Figures 50 through 53 show walls running parallel to the slope and Figures 54 through 56 show walls at the high end of the slope.

1. *EPDM Flashing at Sidewall.* This detail is simple but effective (Figure 50). The EPDM flashing creates a weathertight seal and allows for thermal expansion and contraction of the roof panels in relation to the wall. (Armco Building Systems)

2. *Metal Flashing at Sidewall.* This detail has a serious flaw—the roof-to-wall flashing is fastened directly to the parapet wall and to the roof panel (Figure 51). Longitudinal thermal expansion and contraction of the roof panel would tear the flashing either from the wall or from the roof panel. (American Buildings Co.)

3. *Metal Flashing With Slip Joint at Sidewall—Example 1.* In this design, the slip joint between the roof and wall flashings allows longitudinal thermal movement of the roofing panels independent of the sidewall. The manufacturer suggests that the roof flashing overlap two panel ribs rather than just one (as shown in Figure 52) to create an internal safety gutter that will catch leaks. The roof flashing can be as long as desired since it will expand and contract along with the roof panel. Since the wall flashing is attached to the wall structure, it should be in sections no longer than 10 to 12 ft so that the total longitudinal thermal expansion and contraction of each section is small. (H. H. Robertson Co.)

4. *Metal Flashing With Slip Joint at Sidewall—Example 2.* The slip joint between the roof and wall flashings allows longitudinal thermal movement of the roofing panels independent of the sidewall (Figure 53). Having the fastener at a low spot in the roof flashing is not a good idea because snow, ice, and other debris could allow water to stand over it; leaks also could occur around poorly sealed fasteners. A better method would be to bring the flashing straight over to the wall from the top of the roof panel seam and then up to the slip joint (as shown in Figure 52). The wall flashing piece should be in sections 10 to

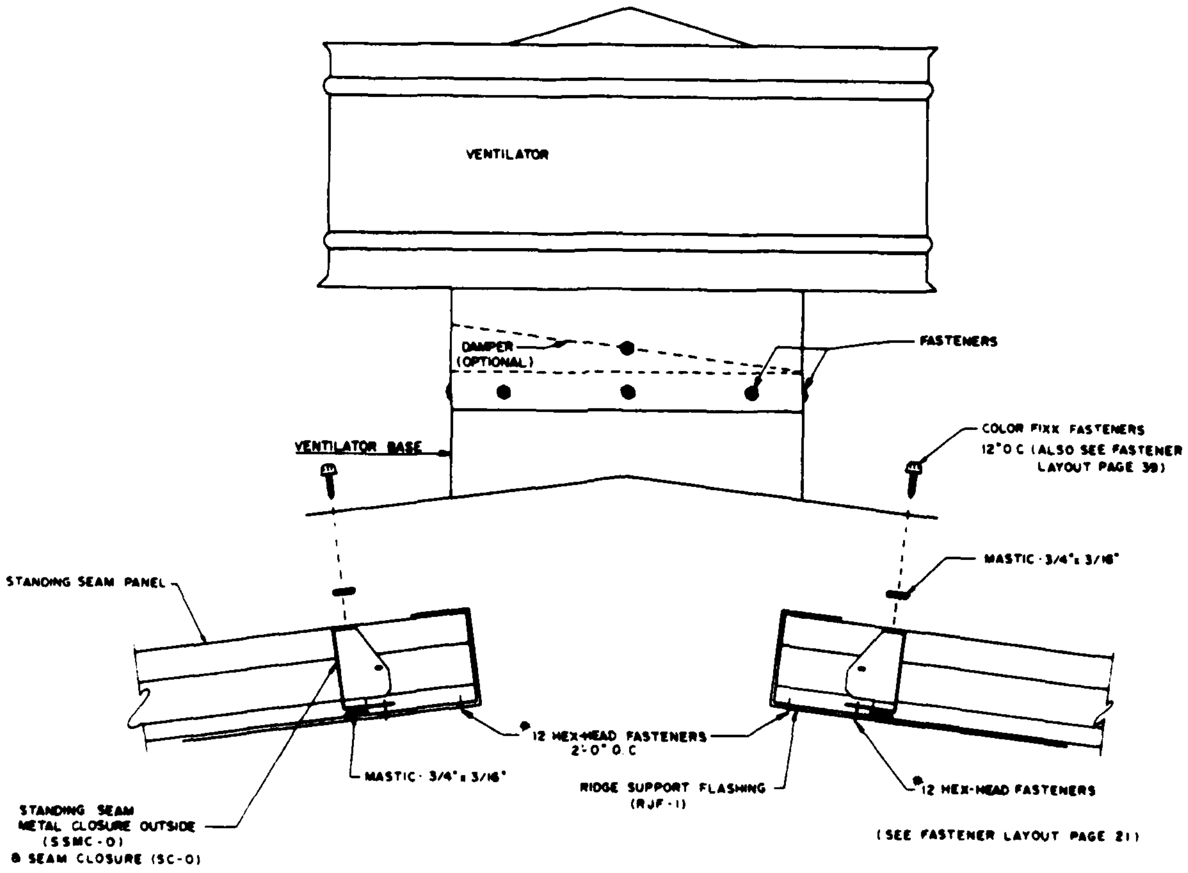
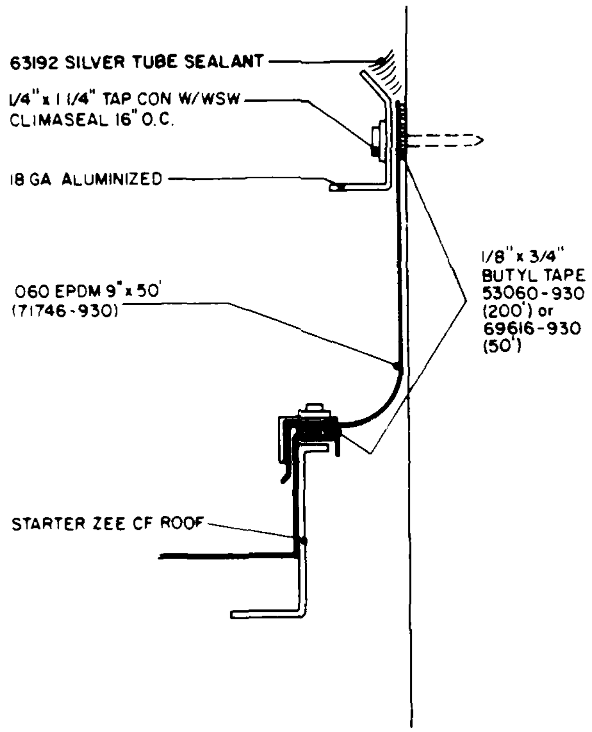
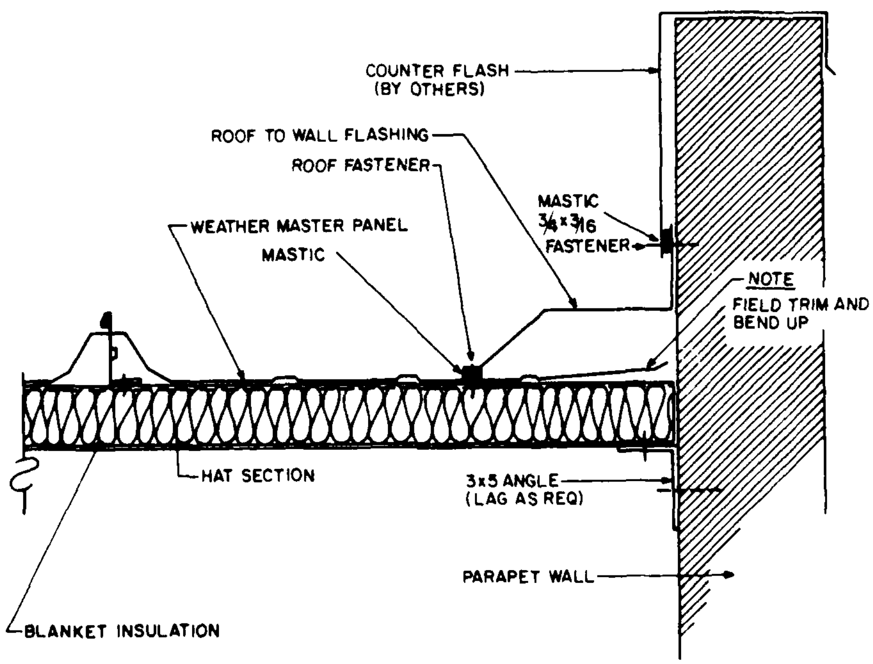


Figure 49. Circular ridge vent.



STARTING END OF BUILDING

Figure 50. EPDM flashing at sidewall.



SECTION AT WALL TO LOWER ROOF

Figure 51. Metal flashing at sidewall.

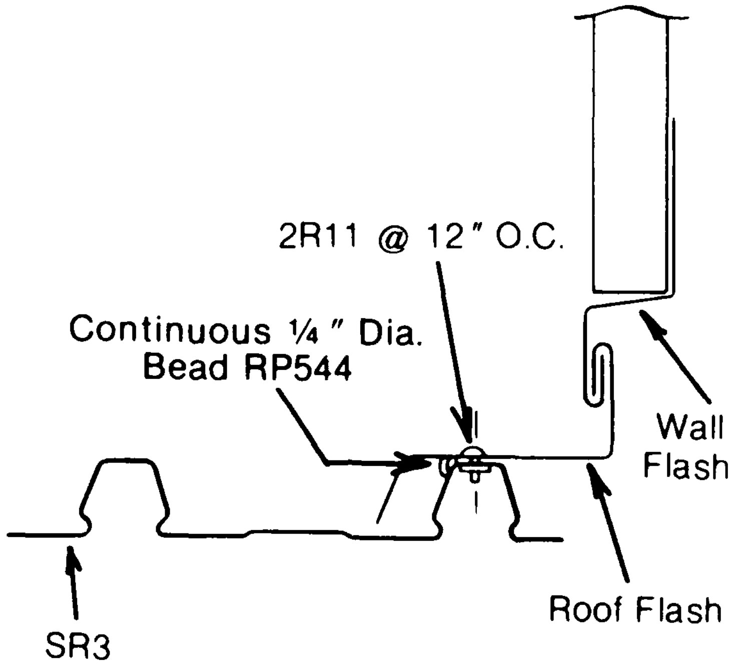


Figure 52. Metal flashing with slipjoint at sidewall example 1.

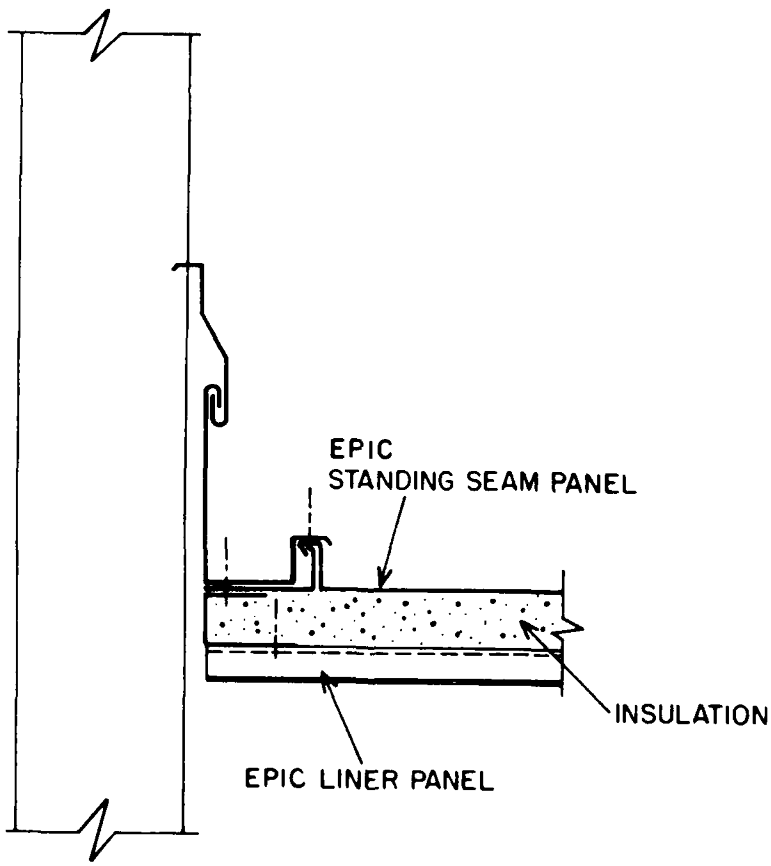


Figure 53. Metal flashing with slipjoint at sidewall example 2.

12 ft long to avoid buckling when it expands and contracts. (Epic Metals Corp.)

5. *Metal Flashing With Slip Joint at Sidewall–Example 3.* The roof panel is secured against uplift forces by the gable clip, yet is allowed to expand and contract freely in the longitudinal direction (Figure 54). The flashing and counterflashing should be limited to 10 to 12 ft lengths to avoid buckling when they expand and contract. An uplift resistance strap keeps the counterflashing from being bent upward by high winds. The fastener used to secure the flashing to the gable clip should have a washer. This detail is shown with a solid substrate but it would work equally well over a purlin substrate. (Zip-Rip, Inc.)

6. *Metal Flashing at Headwall–Example 1.* Two different shapes of headwall flashing are used in this design, depending on whether roof panels are fixed or allowed to move longitudinally at the headwall (Figure 55). The length of the headwall flashing should be limited to 10 to 12 ft to minimize the total longitudinal thermal expansion and contraction per section. (H. H. Robertson Co.)

7. *Metal Flashing at Headwall–Example 2.* The counter- and roof-to-wall flashings are fastened directly to the parapet wall; thus, longitudinal thermal movement of the flashing will be a problem if the flashing is in sections longer than 10 to 12 ft (Figure 56). This design does not allow longitudinal thermal expansion and contraction of the roofing panels. The panels should be fixed at the headwall end and allowed to float at the eave end. (American Buildings Co.)

8. *EPDM Flashing at Headwall.* This detail is simple but effective (Figure 57). The EPDM flashing creates a weathertight seal and allows for longitudinal thermal expansion and contraction of the roof panels. If the EPDM flashing is installed with too much slack, a trough that could hold water will be created. This condition, coupled with a poorly sealed lap joint in the flashing, could result in a leak. (Armco Building Systems)

Valley Flashing

Not to be confused with a valley gutter, a valley occurs at the intersection of two sloped roof surfaces and runs from the ridge to the eave, the eave end being at an interior corner of the building. Occasionally, a valley is designed similar to a valley gutter if it will be carrying a high volume of water. Problems can arise with longitudinal thermal movement of a valley and thermal movement of roof panels adjoining the valley since the valley and the roof panels are neither perpendicular nor parallel to each other. The roof panels usually can be fixed at or near the valley and allowed to "float" at their opposite ends. If the roof panels are fixed at the ridge, the valley must be designed so that it can flex as the ends of the roof panels move (see detail 2 below). In addition, rigid connections between the valley and the roof substrate should be avoided in this case.

1. *Metal Valley Flashing–Example 1.* This valley flashing is not designed to accommodate longitudinal thermal movement of the roof panels (Figure 58). The valley flashing should have a ridge in the center (as in Figure 59) to keep drainage from washing across the valley and under the roof panel on the opposite side. The flashing edge should be folded up and back on itself to provide an extra barrier in case water does penetrate that far. (H. H. Robertson Co.)

2. *Metal Valley Flashing–Example 2.* This valley flashing is designed to accommodate longitudinal thermal movement of the roofing panels (Figure 59). The ridge in the center of the valley flexes as the roof panels expand and contract. In addition, the ridge keeps drainage from washing across the valley and under the roof panel on the opposite side. The edge of the flashing should be folded up and back on itself to provide an extra barrier to water. The dotted line in Figure 59 shows an alternative box-shaped valley if large amounts of runoff are to be handled. The box valley would flex freely to allow for thermal movement of the roof panels. (H. H. Robertson Co.)

Care and Maintenance: Recoating and Repair

A metal roof needs occasional care and maintenance to ensure that it will last as long as possible. Most manufacturers recommend that the roof be washed approximately yearly with a strong stream of clear water to remove atmospheric dirt which can make the finish appear dulled. Barring unforeseen damage, a yearly washing is all the maintenance the metal roof will require for many years.

Occasionally, a roof will become damaged to the point at which one or more panels need to be replaced. This procedure requires two or more side lap seams to be opened up so that the damaged panel(s) can be removed and replaced. In general, panels secured by three-piece seams have an advantage at this point because adjacent, undamaged panels will be disturbed only mildly, if at all, when a three-piece seam is opened up (Chapter 5 describes seam types). The seam cap for

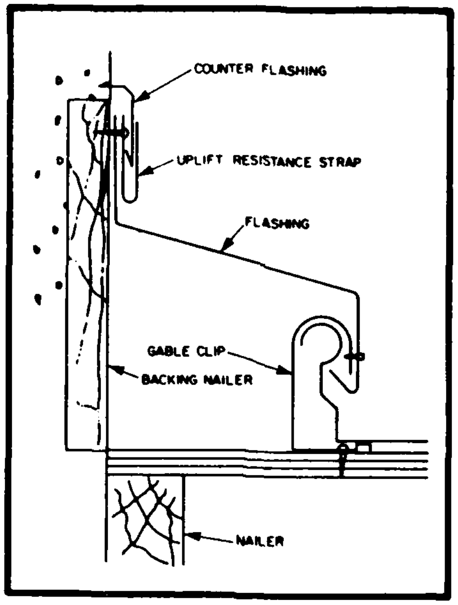


Figure 54. Metal flashing with slipjoint at sidewall–example 3.

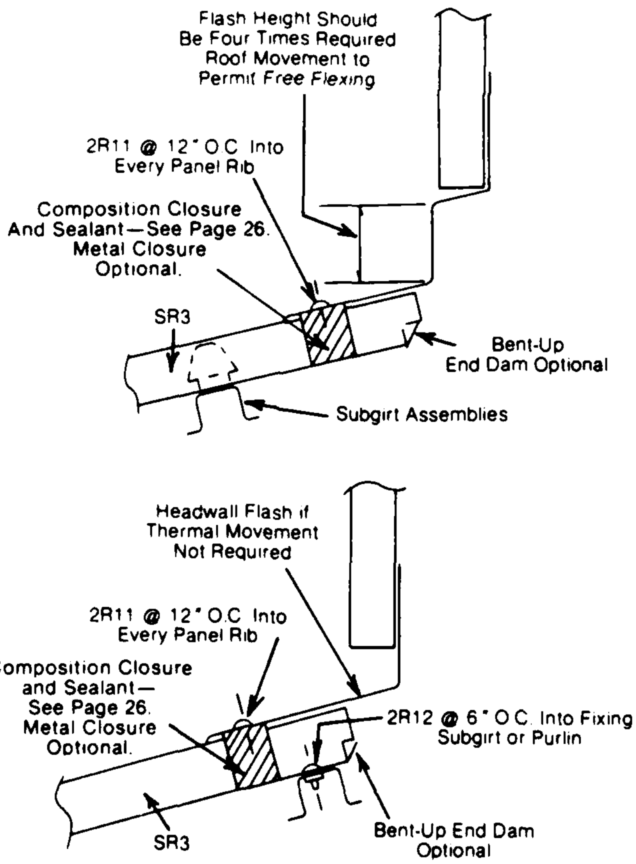


Figure 55. Metal flashing at headwall–example 1.

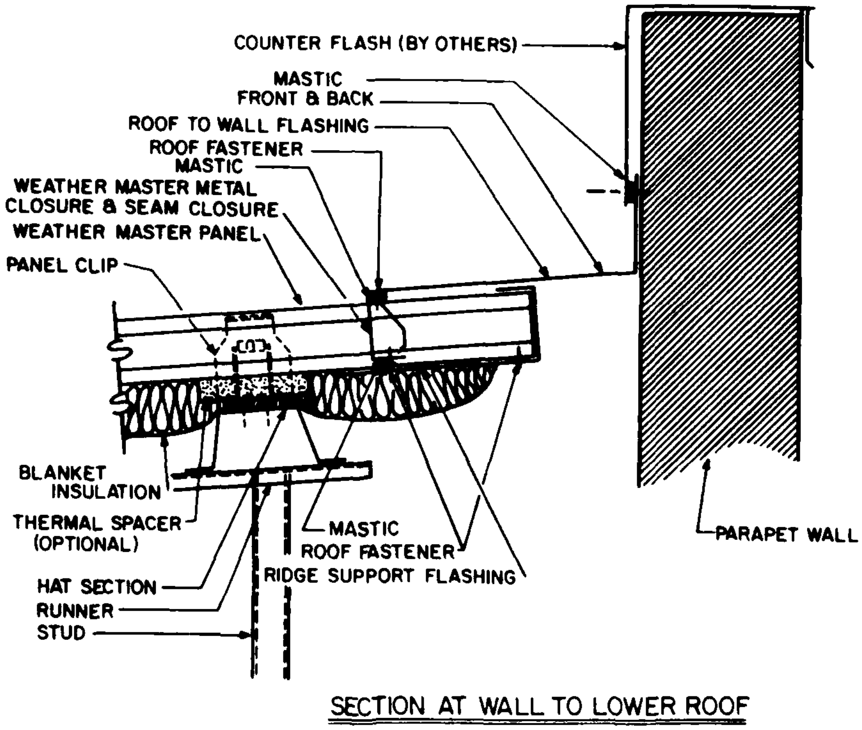


Figure 56. Metal flashing at headwall—example 2.

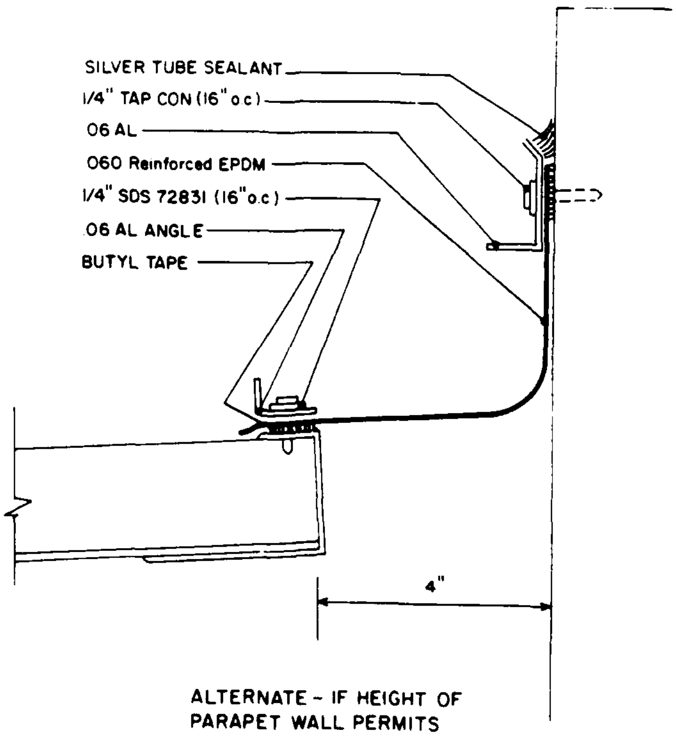


Figure 57. EPDM flashing at headwall.

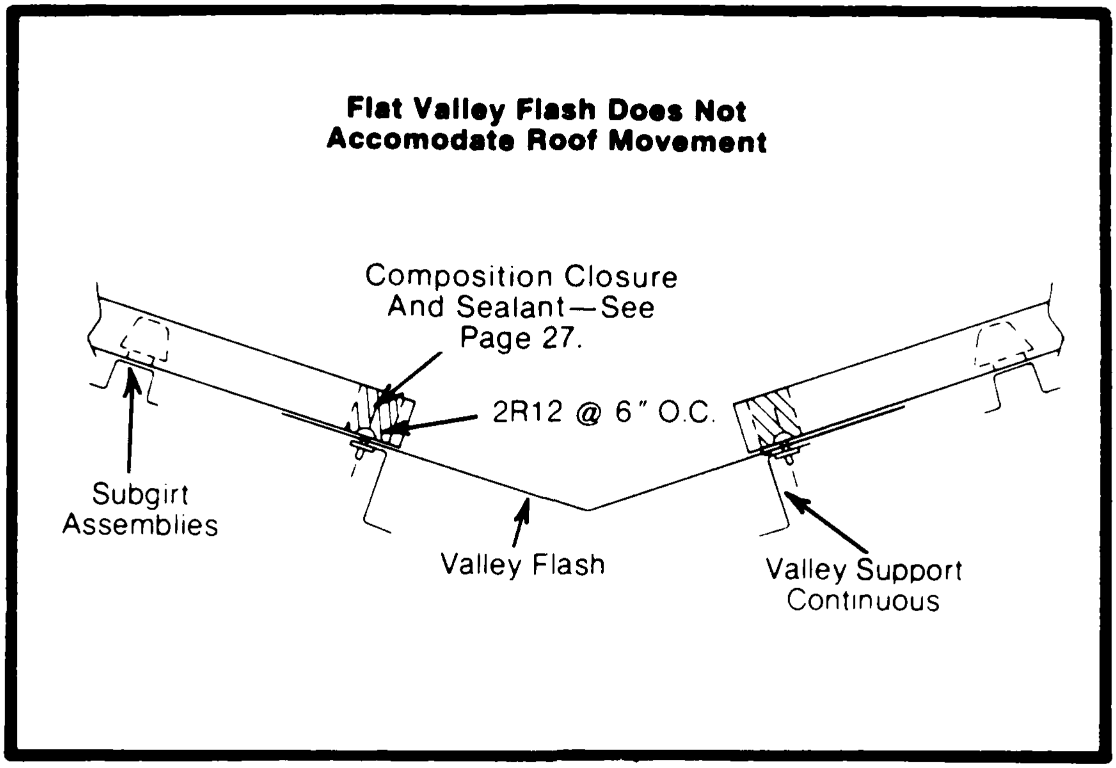


Figure 58. Metal valley flashing example 1

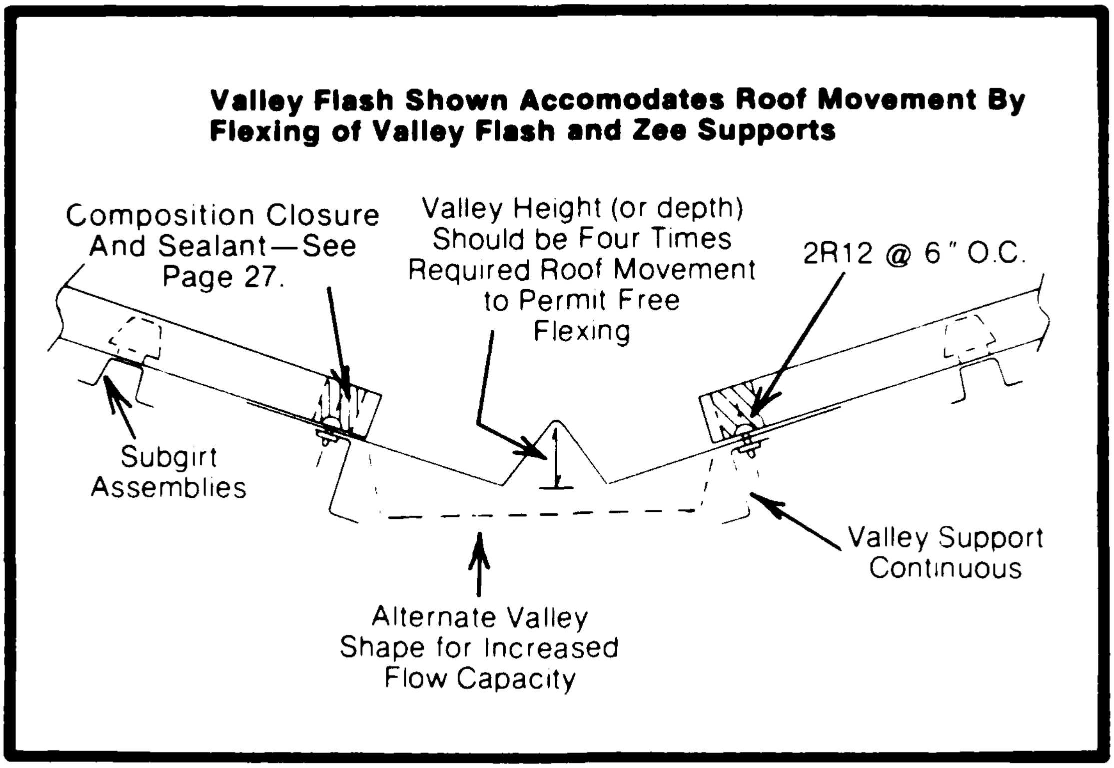


Figure 59. Metal valley flashing example 2.

the three-piece seam is cut along its entire length using an air chisel or other equipment; the damaged panel can then be lifted away and a new panel laid in place. A new seam cap is applied and the procedure is completed.

Panels secured by two-piece seams–particularly those which have been machine-seamed on the roof–usually are more difficult to remove without disturbing adjacent undamaged panels. Some manufacturers supply special tools to use in prying open the seams to remove a damaged panel. Once the damaged panel is removed, the new panel is laid in place and the seams are resealed.

Recoating a corroded or badly weathered metal roof can be an economical alternative to total replacement. The general procedure for recoating requires that any peeling paint and loose, heavy corrosion be removed either by wire-brushing or sandblasting. The entire surface of the roof should then be cleaned thoroughly (the cleaning solution depends on the original finish) and allowed to dry completely. Bare metal and tight corrosion should always be spot-primed; some manufacturers require that the rest of the roof be primed as well. The finish coat is then applied at the manufacturer's recommended coverage rate.

Although cotaings such as urethanes and fluorocarbon polymers often are used in recoating applications, it should be pointed out that these formulations are not the standard factory-applied type. Coatings which are intended to be factory-applied normally require oven-baking to cure properly; thus, these coatings would fail when they are field-applied. The field-applied coatings are said to be specially formulated for air-curing. Manufacturers of these urethanes and fluorocarbons claim that lifespans of the field-applied coatings approach those of the factory-applied, oven-baked coatings.

5 METAL ROOFING CLASSIFICATIONS

Metal roof systems can be divided into two broad categories based on their method of attachment to the substrate exposed fastener and concealed fastener types. Most exposed fastener systems are quite similar in appearance and function, whereas the concealed fastener systems have a wide variety of panel profiles.

Exposed Fastener Systems

The exposed fastener method is the easiest and probably least expensive way to secure a metal roof. The method might better be described as a lap-and-fasten system, in which the panels are lapped at the edges and a screw or nail is used to secure the joint. The fastener is driven through the high point of the lap with a washer to seal the hole (Figure 60).

Exposed fastener systems require that a large number of holes be created in the roof panels to fasten them to the purlins. Steps are taken to seal the fastener holes (i.e., Neoprene washers), but many potential

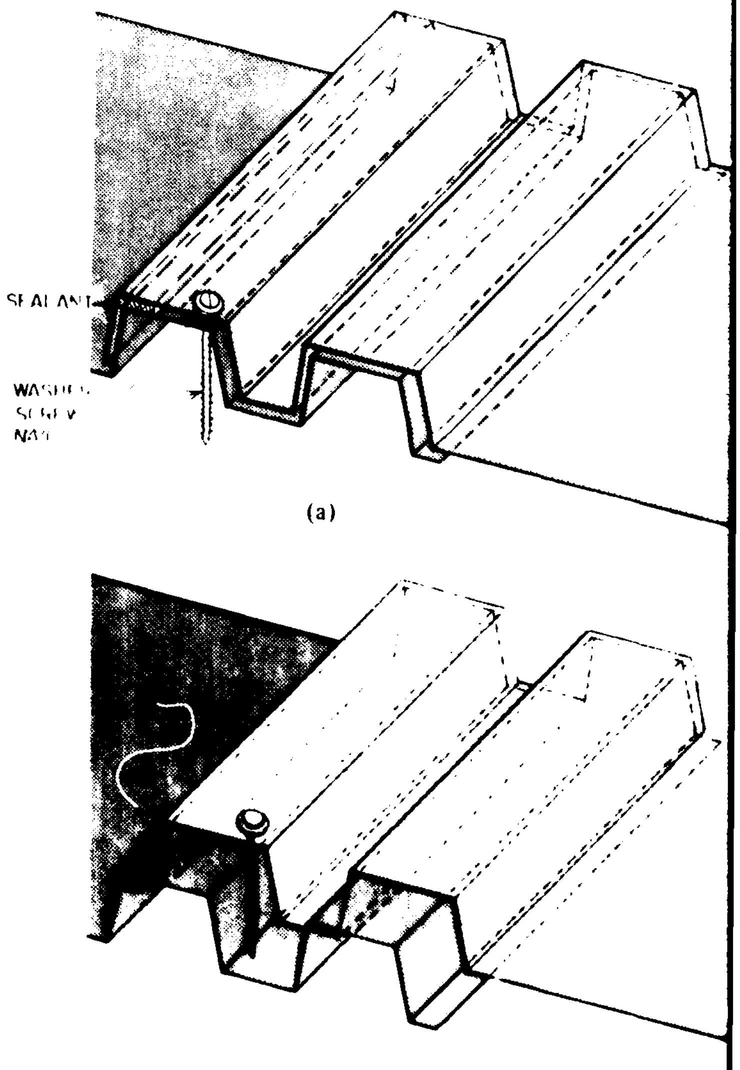


Figure 60. Exposed-fastener seam detail (a) with sealant in seam and (b) with anti-capillary groove in seam.

leak sites remain. Also, temperature fluctuations cause dimensional changes in the roof panels, making the panels slide relative to the purlins at points where the fasteners are not tight enough. This process enlarges the fastener holes so much that the Neoprene washers cannot provide a tight seal. Correct tightening of the fasteners is important to allow the Neoprene washer to seal properly. An overly tight fastener will squeeze the washer out of the joint or possibly tear the washer. In either case, a poor seal is created.

If all fasteners are tightened properly so that the roof panels cannot slide relative to the purlins, then thermal expansion and contraction of the panels are absorbed by a process known as "purlin roll." The purlins (typically Z-purlins) are of a light enough gauge to flex back and forth slightly as the roof panels expand and contract longitudinally. However, if the purlins are inadvertently braced in a way that prevents them from rolling, repeated expansion and contraction of the panels may eventually snap off the fasteners or cause the fastener holes to leak (as described above).

Different methods are used to keep water from creeping under the side lap joint. Some manufacturers rely on factory- or field-applied sealant to create an impervious barrier (Figure 60a) whereas others form an antisiphon or anticapillary groove in the lower panel of the lap (Figure 60b). The groove creates a capillary break to prevent water from being drawn through the seam. In addition, the groove acts as a drain to carry away the water it has trapped.

Concealed Fastener Systems

As the name implies, the concealed fastener system leaves no fasteners exposed to the elements on the longitudinal seams. Stamped metal clips are fastened to the substrate and hold the panels in place at the longitudinal seams. There are three types of clips—two-piece, purlin slip, and panel slip. There are two main types of concealed fastener systems—two-piece and three-piece seam.

Clips

Two-Piece Clips. These clips are used with long, continuous panels that may undergo major thermal expansion and contraction. They consist of an upper part, which is clamped rigidly into the seam, and a lower part, which is fastened firmly to the substrate. The two pieces are connected by a slip joint which allows longitudinal movement of the panels. The ideal two-piece clip is self-centering. When it is installed, it is automatically set to allow equal amounts of movement in either direction. Problems can arise when long roof panels are being installed in extremely hot or cold weather because most of the thermal movement from that time on will be in one direction only. In these cases, the sliding portion of the clip may have to be installed off-center to handle the expected thermal movement.

Purlin Slip and Panel Slip Clips. These clips are used for short panel runs for which little thermal movement is expected. The two clips are basically the same; they differ in the way they are fastened. Purlin slip clips allow for thermal movement in the loose connection between clip and substrate. Panel slip clips are fastened tightly to the substrate and thermal movement occurs when the panels slip relative to the clip. This slippage may cause some local damage to any sealant in the seam, but since the amount of thermal movement is small, the damage should be negligible.

Regardless of which type of clip is used, there is some point along the slope at which the roof panels must be fixed to the substrate or else the panels may "walk" their way down the slope with repeated thermal cycling. Possible fixing points are at the ridge, the eave, or some point near the middle of the slope. If the roof panels are fixed at the ridge or eave, flashing details are simplified at that point because there is no longitudinal movement of the roof panels to accommodate; however, this means the entire range of longitudinal thermal expansion and contraction must be dealt with at the opposite end—and movement can be considerable with very long slopes. A midslope fixing point thus may be desirable on very long slopes to cut in half the maximum amount of thermal expansion and contraction that must be accommodated. In this case, both the eave and the ridge flashing details must account for longitudinal movement of the roof panels but, again, the magnitude of the movement is less than would occur with the panels fixed at the ridge or eave alone.

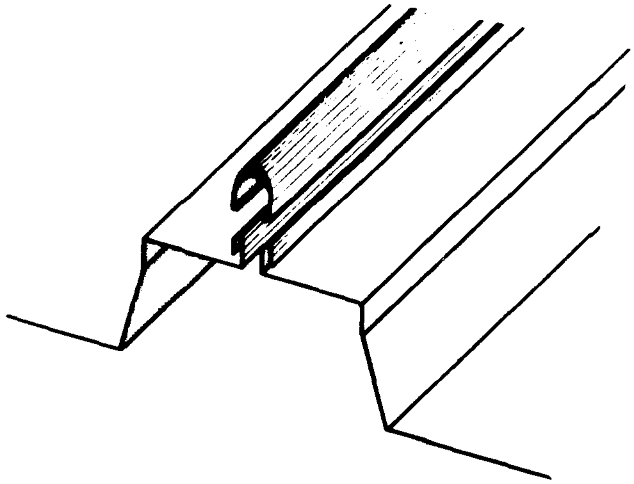
Three-Piece Seams

Components of a three-piece seam include the two adjacent panels and the seam cap. There are a variety of profiles of the three-piece seam, but all are merely variations of three basic approaches—raised, flush, and open seams.

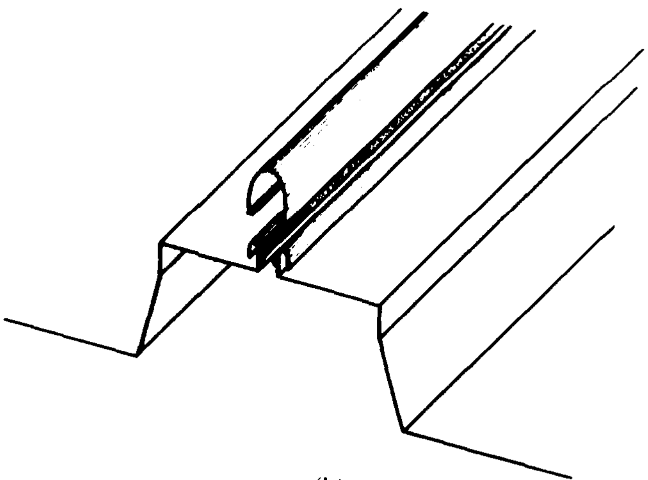
Raised Seam Panel. This panel's seam is elevated as much as 3 in. above the panel surface (Figure 61) and is particularly useful in low-slope applications (down to 1/4 in 12). The seam cap may simply snap into place or it may be necessary to use a portable

seaming machine to create the final weathertight seal. Sealant is usually applied at the factory either in the seam cap (Figure 61a) or on the panel edges (Figure 61b). A profile closure is required at the eave to seal the opening under the raised seam (Figure 62).

Flush Seam Panels. These panels are characterized by the absence of a profile closure at the eave and are manufactured in two basic seam profiles: standing seam (Figure 63) and T-seam. The modern T-seam appears identical to the hand-formed seam shown in



(a)



(b)

Figure 61. Three-piece raised seam detail with factory-applied sealant (a) in cap and (b) on mating edges of panels.

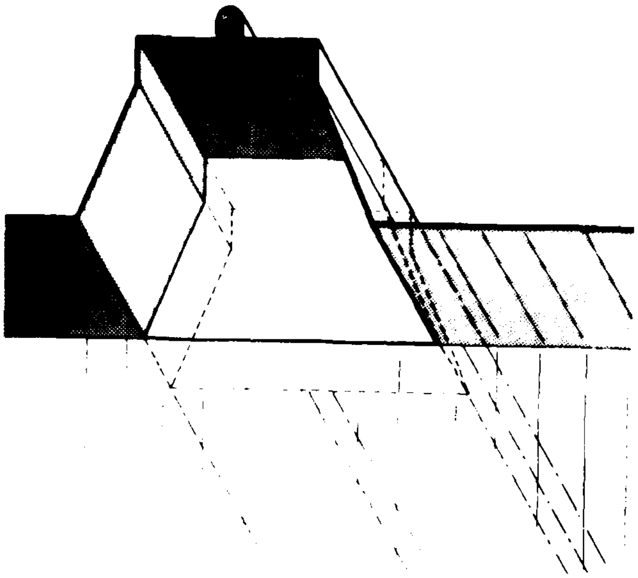


Figure 62. Profile closure at eave support for three-piece raised seam panel.

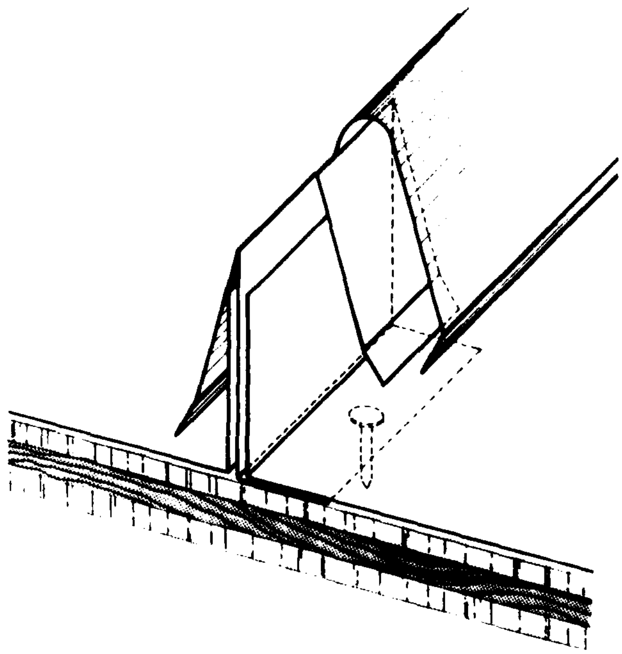


Figure 63. Three-piece standing seam detail.

Figure 5b; the clip used on the newer version of the T-seam is the only difference. Of the three types of three-piece seams described in this section (flush, raised, and open), the flush seam is probably the most secure in that no extra plugs or closures are required at the eave and seam heights up to 3 in. are available.

Open (or Bottom) Seam Panels. These panels (Figure 64) are the modern version of the old hand-formed batten seam panels shown in Figure 5a. A plug or cap is required at the eave to close off the batten. Rather than relying on many interlocked folds of metal to keep the weather out (as with the hand-formed seam), the modern seam depends almost exclusively on the height of the panel's edge above the roof surface. Some panels have their edges turned up as much as 2 in., whereas others have only a 3/4-in. edge lip. The use of open seam panels should be restricted to roof slopes greater than approximately 3 in 12 to prevent standing water that could wash under the batten cap and over the edge of the panels. Many manufacturers produce one panel profile that can be used either with a batten cap or a standing seam cap -- the only difference being the type of clip used between the panels.

Two-Piece Seams

Panels that have a two-piece seam are produced in a wide variety of profiles. They can be separated into broad groups, based on the direction in which the panels bend within the seam and the amount of contact between the panels within the seam. Three main categories into which the two-piece seam systems can be divided are: (1) those in which the two panels nest closely and bend in the same direction with the seam, which will be called Type I (Figure 65); (2) those in which the two panels nest closely but bend in opposite directions within the seam, called Type II (Figure 66 and 67); and (3) those in which the panels nest closely only at a single point within the seam, called Type III (Figures 68 and 69).

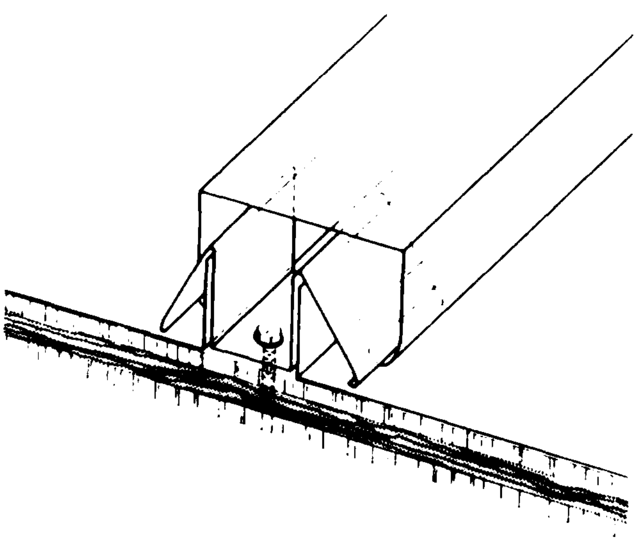
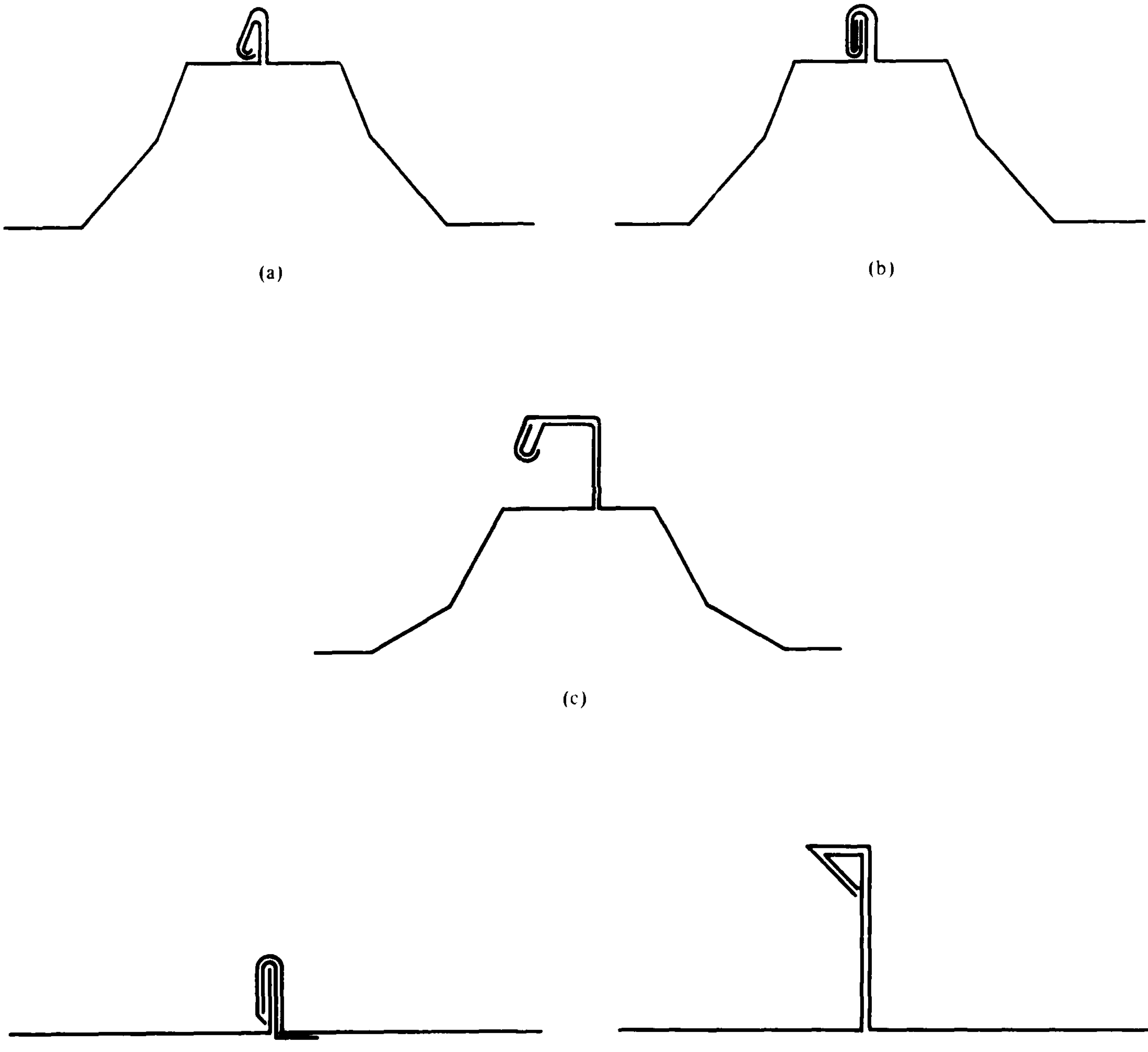


Figure 64. Three-piece batten seam detail.

The Type I group of two-piece seams can be further subdivided into those with raised seams (Figure 65, a through c) and flush seams (Figure 65, d and e). The two-piece Type I raised seam panels have their seams elevated as much as 3 in. above the roof surface and, like their three-piece counterparts, are useful in low sloped applications (down to 1/2 in 12). The final weathertight seam can be created in one of three ways: (1) the female panel edge can snap in place over the male panel edge, with no further attention required (Figure 65a); (2) the male and female panel edges can be laid together loosely at first, with the final seam created by a portable electric seaming machine (Figure 65b); or (3) the female panel can be held vertically while its edge is hooked onto the male edge of the adjacent panel. In the third method, the female panel is then rotated down until it lays flat on the substrate (Figure 23c). All three methods generally use a factory-applied sealant to increase the seam's effectiveness. The two-piece raised-seam panels require a profile closure at the eave end to seal between the eave support and the raised seam.

Two-piece Type I flush-seam panels do not require profile closures at the eave end. There are two basic types of two-piece Type I flush seam panels: those in which the male and female panel edges are snapped together for the final seam (Figure 65d) and those in which the male and female edges are laid together loosely at first, with the final seam created by a portable electric seaming machine (Figure 65e). The snap-together seams usually are 3/4 to 1 in. tall and should be used on roof slopes of 3 in 12 or greater when standing water will not be a problem. Most machine-sealed seams (Figure 65d) are 2 to 3 in. tall and can be used on roof slopes as low as 1/4 in 12. The machine-sealed seam normally contains a bead of factory-applied sealant to increase its resistance to standing water.

Two-piece Type II seams can be divided into flush seams (Figure 66) and open seams (Figure 67). In addition to the seam profile shown in Figure 66, two-piece Type II flush-seam panels are formed in a profile that has a series of concentric circles, rather than



(a) (b)

(c)

(d) (e)

Figure 65. (a–c) Two-piece Type I raised-seam profiles, (d and e) two-piece Type I flush-seam profiles.

interlocking triangles, onto which the panels and clip interlock. The principle is the same in either case; the only difference is in the seam's appearance. The flush seam is typically 2-1/2 to 3 in. tall and can be used on roof slopes down to 1/4 in 12. The flush seam panel's final seam is formed by a portable electric seaming machine and usually contains a factory-applied sealant when the system is used on low-slope roofs.

Two-piece Type II open-seam panels (Figure 67) snap together to create the final seam and normally contain a field- or factory-applied sealant to make the seam more weathertight. This type of seam is typically 1-1/2 to 2 in. tall and can be used on roof slopes as low as 1/4 in 12.

Two-piece Type III seams (Figures 68 and 69) are an attempt to recreate the look of a batten seam panel without the bother of a separate batten cap. Two different types of two-piece Type III seams are produced: one in which the attachment clip has a spring leg that keeps the two panels interlocked (Figure 68) and one in which the two panels are self-interlocking, requiring no help from the attachment clip to remain in contact (Figure 69). Since a seam sealant usually is not used with either type of seam, the amount of weather protection the seam provides is determined mainly by the height of the vertical leg inside the seam (typically 1-1/4 to 1-3/4 in.). The design of the two-piece Type III spring-clip seam (Figure 68) encourages water entry (almost as if it were designed to be a small gutter) and for this reason, a minimum roof slope of 3 in 12 is required. The two-piece Type III self-gripping seam (Figure 69) is more secure because of its small lip that tends to keep most water out of the seam's interior. This type of seam can be used on roof slopes down to 1/4 in 12.

Two-Piece Versus Three-Piece Seams

Three-piece seams have an advantage over two-piece seams when it is necessary to replace a damaged panel. A panel secured by a three-piece seam can be removed by first removing the seam cap at both sides of the panel. The panel can then be lifted off and replaced with little or no damage to adjacent panels. The seam cap may not be reusable, depending on how it was originally applied, but a new seam cap is a minor expense. If a panel secured by a machine-seamed two-piece seam (Figure 65a, 65e, or 66) needs to be replaced, there is a chance that one or both of the adjacent panels may be damaged in the process of opening the seams on the damaged panel. On the other hand, some of the snap-together two-piece seams appear to be very easy to separate, particularly the type shown in Figure 65d. Some manufacturers provide a special tool for unlocking the seam on their panels.

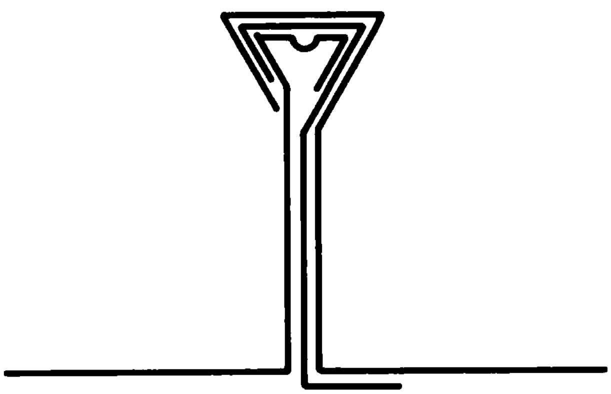


Figure 66. Two-piece Type II flush-seam profile.

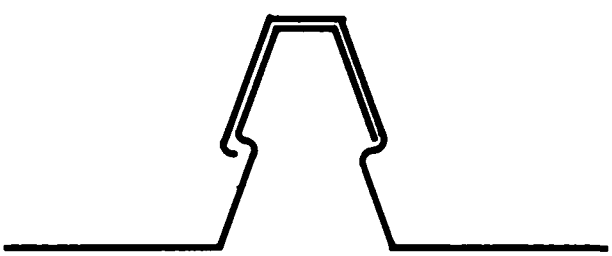


Figure 67. Two-piece open seam profile.

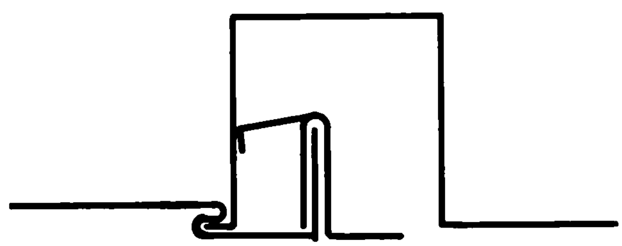


Figure 68. Two-piece Type III spring-clip profile.

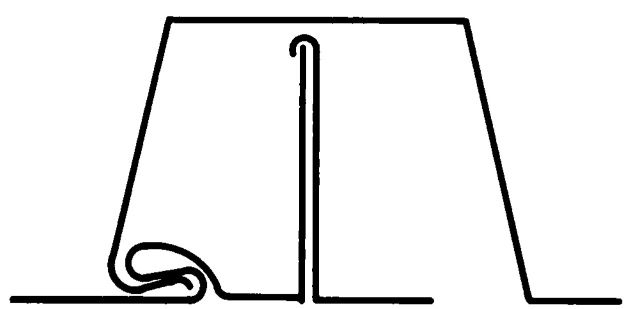


Figure 69. Two-piece Type III self-gripping profile.

A disadvantage of the three-piece seam is that the seam cap is subject to damage or loss on the jobsite before it is applied to the seam.

6 ANALYSIS

By reviewing the literature and details for several metal roofing systems, USA-CERL analyzed the products based on properties considered desirable for all roofs.

Standing seam metal roofing has evolved from a hand-crafted, labor-intensive product to a very mechanized, highly technical system of parts. In contrast to the few standard hand-formed seam profiles formerly available, a wide variety of complex, machine-formed profiles are now manufactured.

Standing seam metal roofing is an excellent system to use under certain conditions: the roof should have relatively few penetrations (e.g., plumbing vent stacks, skylights, and equipment curbs), the roof form should be fairly simple, the roof slope should be no less than 1/4 in 12, and thermal expansion and contraction of the metal roof should be accommodated in the details' design. Given two roofs of the same square-foot area, the roof with more penetrations or a more complex form will be much more difficult to cover with a standing seam metal system. The handling of details constitutes a disproportionate share of the labor in applying a metal roof. Thus, a highly complex roof might be covered more easily with some other system.

The importance of careful detailing cannot be overstressed: Poor detailing can cause a metal roof to literally tear itself apart in a very short time. From the discussion of good and bad points of each detail reviewed in Chapter 4, it should be clear what constitutes a good design.

The classification system proposed in Chapter 5 for these standing seam profiles could be used Army-wide. Logically, similar performance can be expected from similar profiles, so that a classification of this type could help in specifying metal roofing systems.

The exposed fastener metal roofing system is an old method which is still used today. Simply described as a lap-and-fasten system, exposed fastener metal roofing is an economical and effective choice when the clean appearance of a concealed fastener system is not required.

A wide variety of very durable materials is used to manufacture metal roofing. Galvanized or Galvalumed steel with an organic finish coating is probably the most commonly used product for applications ranging from large industrial and commercial to small commercial and residential. The organic coatings are available in a wide range of colors and performance grades. Aluminized steel often is used without a finish coating in large industrial applications because of its durability. Less frequently used are weatherable metals such as copper, stainless steel, or zinc. These metals can be exposed directly to the elements because of their ability to form protective coatings that resist attack and afford extreme durability. The choice of coating or finish will depend on the designer's engineering judgment and the particular application.

It is difficult to make accurate predictions on the life expectancy of the current generation of roofing products. Only in the last 5 to 10 years has the concealed fastener standing-seam system begun to overtake the exposed fastener system as the dominant metal roofing product; thus, the standing-seam systems are still undergoing the changes and redevelopment associated with any new product. Coating systems are continually being improved to afford better resistance to chalking and fading, UV radiation, abrasion, and harsh chemical environments. Seam sealants are being upgraded to increase the sealants' life expectancy to that of the entire roof system. Packaging of sealants is being improved to make correct application an easier task. Although long-term durability data are lacking, many roofing systems reviewed carry 20-year warranties (Table 1), lessening the risks associated with choosing a relatively new product.

7 CONCLUSIONS

A wide variety of complex, machine-formed metal roofing systems are being marketed. Many products analyzed in this investigation would be suitable for use on Army construction; however, the system selected must meet some critical design features:

1. Thermal expansion and contraction must be accommodated.

2. Water must be well drained via effective terminations.

In addition, metal roofing should be considered only for roofs that have (1) relatively few penetrations,

(2) simple form, and (3) a slope no less than 1/4 to 12 (in inches).

Concealed fastener standing seam metal roofing is still undergoing change and redevelopment; however, when the critical design features are met, these systems should provide durable, effective roofing. In addition, many products carry warranties for up to 20 years on the finish system.

All materials are predicted to afford a long service life. In addition, all systems reviewed are almost *maintenance-free*, requiring only a yearly washing to remove any trapped dirt and debris.

Finally, the Army should consider adopting a classification system like the one proposed in this report. This type of system would provide standard criteria for use in specifying metal roofing components.

APPENDIX:

REFERENCE LIST OF MANUFACTURERS

1. A&S Building Systems, Div. of US Industries, Inc.
   10555 W. Little York
   P.O. Box 40099
   Houston, TX 77240

2. Abilene Metal Building Systems
   P.O. Box 3516
   Abilene, TX 79604

3. AEP/SPAN
   P.O. Box 81664
   San Diego, CA 92138

4. Alliance Steel Co.
   8600 W. Reno, Rte. 5
   Oklahoma City, OK 73127

5. American Building Components Co.
   1727 Eastern Avenue
   Cincinnati, OH 45202

6. American Buildings Company
   State Docks Road
   P.O. Box 800
   Eufala, AL 36027

7. American Steel Building Co.
   P.O. Box 14244
   Houston, TX 77021

8. Architectural Mfg., Inc./ Architectural Panels, Inc.
   350 S. Sanford
   Pontiac, MI 48058

9. Arlington Lane Corp.
   2202 E. Randol Mill Road
   Arlington, TX 76011

10. Armco Building Systems
    P.O. Box 46610
    Cincinnati, OH 45246

11. ASC Pacific Inc.
    2141 Milwaukee Way
    P.O. Box 2075
    Tacoma, WA 98401-2075

12. ASC-Omega
    404 E. Dallas Road
    Grapeville, TX 76051

13. Astraline Corporation
    117 Industrial Avenue
    Teterboro, NJ 07608

14. Atlanta Metal Products, Inc.
    829 Hollywood Road N.W.
    Atlanta, GA 30318

15. Atlantic Building Systems, Inc.
    30 Deep Rock Road
    Rochester, NY 14624

16. B & C Steel Corp.
    2535 N. 10th Street
    Scottsbluff, NE 69361

17. Ball Metal & Chemical Co.
    Ball Zinc Products Division
    Greeneville, TN 37743

18. Behlen Manufacturing Co.
    East Highway 30
    P.O. Box 569
    Columbus, NE 68601

19. Berridge Manufacturing Co.
    1720 Maury Street
    Houston, TX 77026

20. Binkley Co.
    12161 Lackland Road
    St. Louis, MO 63146

21. Building Concepts, Ltd.
    702 Overhead Drive
    P.O. Box 26745
    Oklahoma City, OK 73126

22. Butler Manufacturing Co.
    BMA Tower, Penn Valley Park
    Kansas City, MO 64141

23. Ceco Corporation
    P.O. Box 6500
    Columbus, MS 39703-6500

24. Ceco/Delta Building Systems
    P.O. Box 20977
    Dallas, TX 75220

25. Ceco/Engineered Components, Inc.
    P.O. Box Drawer C
    Stafford, TX 77477

26. Ceco/Mitchell Building Systems
    P.O. Drawer 911
    Columbus, MS 39701

27. Century Brand Steel Buildings, Inc.
    P.O. Box 1310
    Jamestown, ND 58401

28. Chief Industries, Inc.
    West Old Highway 30
    P.O. Box 2078
    Grand Island, NE 68802

29. Cincinnati Sheet Metal & Roofing
    1725 Eastern Avenue
    Cincinnati, OH 45202

30. Colorado Steel Building Components
    335 South Summitview Drive
    Fort Collins, CO 80524

31. Corrugated Industries Inc.
    P.O. Box 276
    Chalmette, LA 70044

32. Cot-R-Cap
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101. Whirlwind Steel Buildings
8234 Hansen Road
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102. Zip-Rib Inc.
100 Connecticut Drive
Burlington, NJ 08016

GLOSSARY

acrylic film (Korad) – plastic film 3 mm thick which is heat-laminated to galvanized steel. It resists ultraviolet weathering and remains flexible.

aluminizing - process used by Armco Building Systems in which a layer of pure aluminum is deposited on steel.

anodizing electrolytic oxidation process in which a metal surface is converted to a coating that has desirable protective, decorative, or functional properties. Usually applied only to aluminum.

batten long, narrow strip used to conceal the joints in a butt joint application of flat or corrugated sheets.

brake-pressing – method of cold-forming sheet or strip steel into a desired cross-section.

cap metal piece that covers the butt joint between two roofing panels.

cleat piece of material, such as wood or metal, attached to a structural body to strengthen, secure, or furnish a grip.

coefficient of thermal expansion number indicating the change in length of a material per unit length per degree of temperature change, typically given in units of inches per inch per degree Fahrenheit.

cold-rolled metal that has been shaped using a rolling mill at room temperature.

Cor-ten type of steel made by United States Steel. When exposed to weather, it develops a thick oxide coating that protects it from further corrosion.

cricket any device up-slope of a vertical projection through the roof designed to divert water around the projection.

curb raised edge around a roof penetration.

dry film thickness (DFT) thickness of a coating once it has dried, typically measured in mils.

eave lower horizontal edge of pitched roof.

fluorocarbon coating – type of coating used on metal roofs. It lasts longer and is more durable than polyester enamel.

Galvalume – aluminum/zinc alloy plating used by Bethlehem Steel as a protective coating on mild steel.

galvanic action process that occurs when two dissimilar metals are in contact in the presence of an electrolyte. A minute electrical current is created which dissolves the more reactive metal without harming the more inert metal.

galvanized – coated with a layer of zinc for corrosion resistance.

gauge – number designating the thickness of sheet metal. Over the years, different gauging systems have developed for different metals with the result that a particular gauge of one metal may be a different thickness than the same gauge of another metal. The solution to this problem is to specify sheet metal by its dimensional thickness rather than its gauge number.

hip intersection of two sloped planes on a pitched roof forming a line from the ridge to an exterior corner of the building.

MBMA Metal Building Manufacturer's Association.

mil unit of measure equal to 0.001 inch.

mill finish nonuniform finish on metal which may not be entirely free from stains or oil.

parapet that portion of a building's vertical wall which extends above the roof line at the intersection of the wall and roof.

pitting corrosion of a metal surface, confined to a point or small area, that takes the form of cavities.

polyester enamel type of paint used on metal roofs. It is the least expensive and also the least durable coating.

purlin horizontal structural member attached to the main framing members; supports roof panels.

rake – exposed sloped edge of a pitched roof.

ridge – upper horizontal edge of a pitched roof.

roll-forming – method for forming metal roofing. It is faster than brake-pressing and has the advantage of allowing a greater variety of shapes.

sandwich panel – composite panel consisting of interior and exterior metal faces with an insulating core.

scupper – opening in the wall of a building to allow the water to drain off a flat roof.

sealant – any material used to seal cracks, joints, or laps.

slope, grade – incline of a roof expressed as a ratio of the number of inches of vertical rise per horizontal foot. Also expressed in percent.

stainless steel, Dead Soft Type 304 18/8 – type of stainless steel typically used for roofing; contains 18 percent chromium and 8 percent nickel.

standing seam – generic term used to describe any of several types of roof seams that rise above the roof's surface, as opposed to a seam that lays flat on the roof or is flush with the surface.

substrate – part of the roof structure directly under the roof panels; provides support for the roof panels.

swage – forceful stretching or compressing of a component to afford a close fit.

Terne-Coat – lead/tin alloy coating for other metals manufactured by Follansbee Steel Corp.

UL – Underwriter's Laboratory.

uplift – wind load on a building which causes a load in the upward direction. The UL assigns three ratings (30, 60, and 90, 90 being the best) on the basis of how well a roof resists uplift forces.

valley – intersection of two sloped planes on a pitched roof forming a line from the ridge to an interior corner of the building.

vapor retarder – membrane placed within an assembly to reduct the passage of water vapor through the assembly.

Z-purlin – semiflexible metal purlin with a Z-shaped cross section; allow for some movement of the roofing due to temperature changes.

Zincaluming – process patented in Australia; identical to Galvaluming.

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